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Effectiveness of Fences and Underpasses on the Trans-Canada Highway and Their Impact on Ungulate Populations Project

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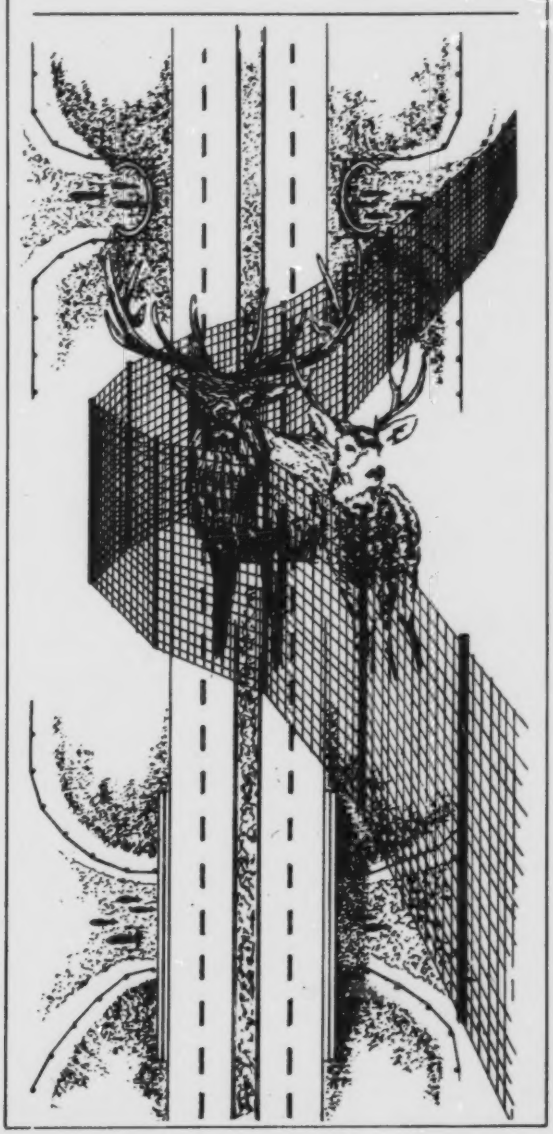

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EXECUTIVE SUMMARY

During the period 1983-87, a 26.1 km segment of the Trans-Canada Highway was twinned from the East Gate of Banff National Park to a point 1.6 km west of the Sunshine Interchange. Before twinning, this section of highway had a history of frequent collisions between vehicles and wildlife. To keep bighorn sheep, elk, moose, mule deer, and white-tailed deer from crossing the road surface, the construction project included a 2.4 m ungulate-proof fence and associated structures along both sides of the road. To allow access between ranges divided by the highway, 8 wildlife underpasses were installed to permit animals to cross beneath the fenced corridor. In addition, ungulates were able to cross the corridor under 3 bridges built primarily as watercourse bridges and over a railway overpass.

Fencing reduced ungulate collisions on the twinned highway by 94 to 97%. Fencing may have facilitated coyote predation on bighorn sheep in 1 area. When a section of the project was twinned in advance of fencing, bighorn sheep and elk road-kills increased significantly.

All available underpasses were used by ungulates. Radio collared elk were little affected by the project in terms of familiar area use, migration routes, and migration timing. Elk crossed the twinned highway corridor less frequently after fencing.

Road-kills on the Trans-Canada Highway were dissimilar from train-kills in the park in terms of species composition, timing, and age structure.

Ecological data including detailed population benchmarks for elk are presented. These data are compared to earlier elk studies in the park and are used to project the population response to twinning and fencing. This assessment showed that the project effectively reduced ungulate road-kills on the twinned highway with little impact on elk movement behavior or elk mortalities from natural causes. The implications for other highway projects are discussed.

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1.0 INTRODUCTION

1.1 PROBLEM DEFINITION

Since the mid 1970's, collisions between vehicles and large mammals on the Trans-Canada Highway (TCH) and the Canadian Pacific Railway (CPR) in the Bow River valley of Banff National Park (BNP) have been a concern of the Canadian Parks Service (CPS) (Kutzer 1972, Kutzer 1974, Flygare 1979, Holroyd 1979, Harrison et al. 1980, Damas and Smith 1982, Holroyd and Van Tighem 1983). This problem was examined in detail during environmental reviews of proposals by Public Works Canada (PWC) to expand the TCH traffic capacity by twinning a 26.1 km segment between the park's eastern boundary and a point 1.6 km west of the Sunshine Village Interchange (Klenavic 1979, Paradine 1982). Subsequent assessments by Logan (1986), Browne et al. (1988), and Flaa (1989), considered the impact of twinning the remaining TCH in the park.

These reviews identified public safety and ungulate population declines as primary concerns on the TCH. Klenavic (1979) noted that effective mitigation would be required whether or not twinning went ahead. The reviews also identified a concern that the road-kill rates might increase on the twinned highway if appropriate mitigation measures were not put in place.

Assessment of existing and potential road-kill problems on the TCH was complicated by 3 factors. First, the ungulate population is a multi-species system involving bighorn sheep (*Ovis canadensis*), elk (*Cervus elaphus*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*). Secondly, these ungulate populations are subject to several potentially additive sources of man-related mortality including: ungulate-vehicle collisions on the TCH, collisions on other park roads, collisions on the CPR, and if animals move outside the park, sport hunting. And lastly, there was little precedent for mitigation of a highway or railway impact in a situation similar to BNP.

Although the construction and operation of highways across ungulate ranges is a concern to many wildlife managers (Kelsall and Simpson 1987), most studies have focused on deer collisions (Puglisi et al. 1974, Bashore et al. 1985, Feldhamer et al. 1986). There are few reports of multi-species problems or of elk road-kills (Singer 1975, Ward et al. 1980).

The literature on ungulate-railway collisions is almost non-existent. Child (1984) described a moose-railway collision problem in northern BC and noted that very little is known about railway-ungulate collisions. Van Tighem (1980) described a railway-ungulate collision problem in Jasper.

Attempts to mitigate highway impacts in other areas have included exclusion fencing and associated structures for deer (Reed et al. 1974, Falk et al. 1978, Feldhamer et al. 1986), underpasses to encourage deer and mountain goats (*Oreamnos americanus*) to cross beneath highways (Reed 1981, Singer 1975), reflectors and whistles to alert deer to the approach of a vehicle (Woodard et al. 1973, Schafer et al. 1984, Schafer and Penland 1985), habitat manipulation to reduce highway attractiveness or to lure wildlife away from highways (Wood and Wolfe 1988), and highway signs to alert motorists to hazardous wildlife crossing areas (Pojar et al. 1975, Coulson 1982).

In their evaluation of the Banff situation, CPS and PWC decided to mitigate the road-kill problem by installing an ungulate-proof fence

along both sides of the twinned highway. To minimize movement behavior disruption, a series of wildlife underpasses were incorporated into the design. These underpasses were intended to allow animals to safely cross beneath the twinned highway and its fenced corridor.

Recognizing that the fencing and underpass mitigation in the park was partially experimental, CPS and PWC also embarked on an adaptive management research and monitoring program to evaluate the success of the mitigation and its implications for future mitigation on the remaining section of untwinned highway in the park. This study is part of the evaluation.

1.2 RESEARCH HYPOTHESES AND QUESTIONS

A specific management hypothesis was not stated before the fences and underpasses were installed. The implied management hypothesis for the fencing-underpass project (B. Leeson, CPS, pers. commun.) was that:

"The fence-underpass system installed along the twinned highway in BNP will reduce ungulate-vehicle collisions while minimizing interference with ungulate population characteristics such as movement behavior and natural mortality sources."

As recognized by Hauge and Keith (1981), assessment of ecological problems such as this require simultaneous investigation of movement behavior, population dynamics, food habits, and habitat utilization. This study adopts this approach.

Several research questions stem from the management hypothesis:

- Did the fence effectively reduce the number of road-kills?
- Did the fence reduce ungulate mortality rates?
- Did twinning increase road-kill mortality rates before the fence was installed?
- How does train-kill mortality compare with highway road-kill mortality?
- Did ungulates use the wildlife underpasses?
- Did the underpass system allow free access to seasonal ranges and migration routes?
- How do current ungulate population parameters compare with benchmarks established in earlier park studies and with the literature on other populations?
- What is the long-term potential impact of the fencing-twinning project on ungulate populations?

Funds were not available to study comprehensively all of the species potentially effected. Elk were chosen as the primary study animal because they were the most abundant ungulate adjacent to the TCH and the species most frequently involved in vehicle-ungulate collisions (Woods 1986a). Earlier studies of elk in the park (Mair 1952, Green 1957, Flook 1967, Struthsaker 1967, Jacobson 1982, Bobek et al. 1983, Holroyd and Van Tighem 1983, and Morgantini 1988) and on-going research by the park warden service provided a rich source of comparative data. Various aspects of this project have been reported on in part in Bottini et al. (1986), Bottini (1987a, 1987b), Woods (1986a, 1986b, 1988), Woods and Hlady (1988), and Woods et al. (1988).

The objective of this research was to address the management hypothesis and to assess the applicability of the mitigation methods to other highway projects of similar scope. The most obvious application would be to the twinning of the remainder of the TCH through the park.

1.3 ACKNOWLEDGEMENTS

This study was a cooperative venture between PWC (Edmonton), the Natural History Research Division (CPS, Calgary), the Resource Conservation section of BNP (CPS, Banff), and the Department of Zoology, University of BC where the author was a graduate student. Funds to allow additional railway surveys were provided by CP Rail (Calgary).

Dr. Bruce Leeson (CPS, Calgary) suggested the project and was a constant source of moral support and professional advice. Dr. A.R.E. Sinclair was the chairman of the author's graduate committee and provided academic guidance.

At the field level, the Banff Warden Service, and the Senior Wildlife Wardens (B. Browne, R. Kunelius, and T. Skjonsberg) in particular, were constantly involved in the study. They directed the collaring program and assisted in innumerable ways in field data collection. Senior Warden Perry Jacobson kindly made the field observations from an earlier elk telemetry project available to the author. In addition, the warden service directed the bighorn sheep component of the highway mitigation project and conducted parallel studies of underpass use, fence intrusions, and canid ecology. Without the on-going advice, co-ordination, and expertise of the warden service, this study would not have been possible.

In addition, the following organizations assisted in locating ungulates killed on the TCH and CPR: Alberta (AB) Fish and Wildlife, Canmore Office; AB Highways, Canmore Office; AB Parks and Recreation, Bow Valley Provincial Park Office; CP Rail, Banff; and, the Royal Canadian Mounted Police, Banff and Canmore Detachments. BC Parks, Mount Assiniboine Provincial Park, kindly allowed us to extend the study into their jurisdiction.

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Special recognition is due Hälle Flygare of Canmore, AB. Hälle carefully pieced together much of the earliest data on the road-kill problem in the park and later braved many challenging working conditions and long hours as the principal contract technician during this study.

2.0 THE STUDY AREA

2.1 STUDY AREA DEFINITION

The study was centred on the main valley of the Bow River in BNP. The Bow Valley Elk Range (BVER) was defined as that area stretching alone the bottom of the Bow River between the Continental Divide in Kicking Horse Pass and the first Canmore intersection along the TCH 4 km east of the BNP East Gate (Figure 1). The BVER has an area of approximately 330 km^2 below the elevation of 1700 m. The BVER is well known as traditional ungulate range and is seasonally important as one of the most extensive elk winter ranges in AB. The BVER conforms to the elk census area routinely surveyed by the warden service (Kunelius 1985).

The BVER definition is one of convenience. However, since it occupies a discrete watershed in very rugged mountainous terrain, there is limited opportunity for ungulates to move between the BVER and other elk populations during the winter. Radio tracking has documented movements between the BVER elk population and several other elk wintering areas including the Columbia, Kicking Horse, and Kootenay river valleys in BC and the Red Deer River valley in AB (H. Abbott and R. Kunelius, CPS, pers. commun., Morgantini 1988, and this study). To the east, the BVER arbitrarily ends at Canmore although elk winter range continues for at least another 35 km.

Seasonal elk migrations from the BVER up tributary valleys of the Bow River defined several auxiliary study areas. These included the watersheds of Brewster Creek, Spray River/ Bryant Creek, Forty Mile Creek, and Cascade River/Stoney Creek. Migrations from the BVER over the Continental Divide into BC have identified additional study sites in the Kootenay River watershed in Kootenay National Park, the Kicking Horse River valley in Yoho National Park, and the Mitchell Creek/ Simpson River watersheds in Mount Assiniboine Provincial Park. On these seasonal ranges, elk from other winter ranges may intermingle with elk from the BVER.

For the purpose of analyzing ungulate-vehicle collisions on the TCH, the area between Canmore and Seebee was included in this study.

2.2 THE BIOPHYSICAL ENVIRONMENT

The BVER is within the Continental Ranges of the Southern Rocky Mountains (Figure 1). The area forms a rough parallelogram which trends from southeast to northwest for approximately 80 km, extending from 51°00' to 51°30'N and from 115°20' to 116°00'W. The valley bottom elevation increases from 1,341 m at Canmore to 1,646 m at the Continental Divide and the valley floor width varies from 2-5 km. The mountains rise to elevations of 3,000+ m on either side. Of the total area of the BVER below 1700 m, approximately 200 km^2 are between Canmore and Castle Junction and 130 km^2 between Castle Junction and the Continental Divide in Kicking Horse Pass.

This area of the Rocky Mountains has a continental climate characterized by relatively long winters and short summers (Holland and Coen 1983). Although winters can have periods of extreme cold, milder conditions prevail when westerly air-flows dominate. Summers are generally cool with occasional hot spells. Prevailing winds are from the west and there is a general wet to dry precipitation gradient from west to east. Precipitation generally decreases above and below elevations of approximately 2,300 m.

Weather and snowpack data throughout the study period were collected by Environment Canada weather stations near either ends of the BVER at Banff and Lake Louise townsites

(Appendices 1-4). In addition, the warden service gathered snow depth data from the Sunshine Ski Resort and the Mount Norquay ski resort (Appendix 5). Sunshine Ski Resort data approximates the Mount Assiniboine meadows and the meadows near Bourgeau Lake. The Mount Norquay station approximates the lower slopes of the meadows along the northwest flank of Cascade Mountain. The higher slopes north of Cascade Mountain and in the Palliser Range were windswept and rarely had a continuous snow cover in winter.

Mean annual snowfall decreases to the southeast from 418 cm at Lake Louise to 249 cm at the townsite of Banff. Snowpack was greatest at Lake Louise and least east of Banff townsite (Figure 2). During all 4 winters of the study, total winter snowfall was below the long-term average (58-83%). The greatest snowfall in the last 20 years happened in 1971-72 (Appendices 1-4). At Banff, this maximum snow year had snowfall 221% above the highest observed during any year of this study and a snowpack 302% greater.

The BVER is subject to frequent chinooks during the winter and the southeastern third is frequently snow free. The complexity of mountain climate makes generalizations difficul. as extreme swings in weather are frequent.

Wildlife resources of the BVER have been reviewed by Holroyd and Van Tighem (1983). The area is noted for its variety and abundance of ungulates, large carnivores, and avian scavengers. BVER ungulates in approximate order of abundance include elk, bighorn sheep, mule deer, white-tailed deer, mountain goat, and moose. Large carnivores include coyote *(Canis latrans)*, grizzly bear *(Ursus arctos)*, timber wolf *(Canis lupus)*, black bear *(Ursus americanus)*, cougar *(Felis concolor)*, and wolverine *(Gulo gulo)*. Avian scavengers include common raven *(Corvus corax)*, black-billed magpie *(Pica pica)*, bald eagle *(Haliaeetus leucocephalus)* and golden eagle *(Aquila chrysaetos)*.

2.3 THE LAND CLASSIFICATION SYSTEM

Detailed descriptions of the biophysical characteristics of BNP were presented by Holland and Coen (1983) and Holroyd and Van Tighem (1983). This classification system and biophysical overview has been adopted in the current study. Achuff et al. (1984) present a similar treatment for the Kootenay River area. This biophysical description and mapping system is not available for areas outside national parks. A more general biophysical review is available for Mount Assiniboine Provincial Park (Peepre 1983). Forest cover maps are available for AB provincial lands.

The national park land classification system is hierarchical with categories based on land form and soil taxonomies plus vegetation types. The units are called ecoregions, ecosections, and ecosites proceeding from the highest to lowest levels of generalization. The 3 ecoregions are based on vegetation structure and plant species. The 55 ecosections are subdivisions of ecoregions based on broad land form, drainage class and soil differences. The 124 ecosites are based on specific soil and vegetation differences. In addition, there are 8 miscellaneous landscape types (e.g. glacier, gravel pits). A complete description of the units is given by Holland and Coen (1983). Within the BNP segment of the BVER, approximately 200 km^2 are within the montane zone and 130 km^2 within the lower subalpine.

Ecoregion, ecosection, and ecosite representation in the BVER is highly atypical of BNP. The BVER has a greater percentage of habitats important as ungulate winter range than any other area of the park (Holland and Coen 1983).

2.4 ECOREGION DESCRIPTIONS

The Montane Ecoregion (1,311 to 1,600 m) is the warmest and driest and has the greatest temperature fluctuations. Chinooks coupled with low snowfall result in intermittent periods with no snow on the ground during winter. Detailed weather data are available from the Banff townsite. Open forests are dominated by Douglas Fir *(Pseudotsuga menziesii)*, white spruce *(Picea glauca)*, lodgepole pine *(Pinus contorta)*, aspen poplar *(Populus tremuloides)*, and natural grasslands.

The Subalpine Ecoregion (1,600 to 2,300 m) is cooler and wetter than the Montane and has a narrower range of temperature fluctuations. Although the summer maximum temperatures are lower than in the Montane, temperature inversions, especially in winter, can result in higher temperatures in the subalpine (Peepre 1987). Detailed weather data are available from the Lake Louise townsite. In addition, at Mount Norquay, Lake Louise, and Sunshine Village ski areas, snowfall and temperature data are available.

The Subalpine is divided into the Lower Subalpine (1,600 to 2,000 m) and the Upper Subalpine (2,000 to 2,300 m). The Lower Subalpine is a closed evergreen forest with Engelmann spruce *(Picea Engelmannii)*, and subalpine fir *(Abies lasiocarpa)* in mature stands and lodgepole pine in sub-climax stands. In winter, snow cover is continuous. The Upper Subalpine is a transitional zone to the Alpine. With increasing elevation it becomes progressively cooler and wetter with more snowfall and exposure to wind. The forest becomes increasingly more open as it gives way to the treeless Alpine. Exposed areas in the Upper Subalpine can be swept clear of snow in winter.

The Alpine Ecoregion (2300 m+) is generally the coldest ecoregion but temperature inversions during winter can result in higher daytime temperatures than in other ecosections. The greatest precipitation occurs at the Subalpine/Alpine interface and may decrease with increasing elevation. This is the windiest zone in the BVER. Lee slopes may be snow covered all winter, but cliffs and exposed slopes may be snow free. There are no detailed weather data available for alpine areas adjacent to the BVER.

2.5 HUMAN DEVELOPMENTS

The TCH and CPR roughly parallel the Bow River through the study area (Figure 1). They traverse the Montane ecoregion from the east boundary to Castle Junction and the Lower Subalpine ecoregion between Castle Junction and the Continental Divide.

A. Trans-Canada Highway after twinning. Note parallel Canadian Pacific Railway line to right. Photograph by Doug Leighton.

At 3 locations the CPR crosses the TCH and elsewhere has a maximum separation from the highway of 1 km. The TCH and CPR are major transcontinental transportation routes with large traffic volumes. The entire area is heavily visited by tourists and contains an extensive network of public trails, campgrounds, picnic facilities, and secondary roads. Fifteen km west of the park's eastern boundary, a portion of the valley is occupied by the Banff townsite with a resident population of approximately 6,000 and a peak summertime population including tourists of 24,000.

For study purposes, the TCH was considered in 3 zones within the park: TCH I from km 0 to km 11, TCH II from km 11 to km 26.1, and TCH III from km 26.1 to km 80.2 (Figure 1). Significant highway features are given for all zones of the Appendix 6. Complete details on project construction are available from Public Works Canada, Trans-Canada Highway Project, Box 1355, Banff, AB., TOL OCO.

Traffic data were available from several monitoring stations run by Alberta Transportation and Environment Canada within the park (Appendices 7-8). The East Gate station was used in this presentation because of its long history and the known relationship to other stations (Brunnel 1982, M. Brunnel, CPS, pers. commun.).

In 1982, a two-lane undivided highway, with an average speed limit of 90 km/hour and a maximum annual average daily traffic (AADT) of 10,540 vehicles (Appendix 7) ran the length of the BVER. During the years 1983-85, TCH I and II were expanded to a four-lane divided highway with speed limits up to 90 km/hour and a maximum AADT of 11,234. The TCH in zone III was not substantially altered during these periods. Traffic volumes on the TCH peak in July and August and are at a minimum in January and February (Appendix 8).

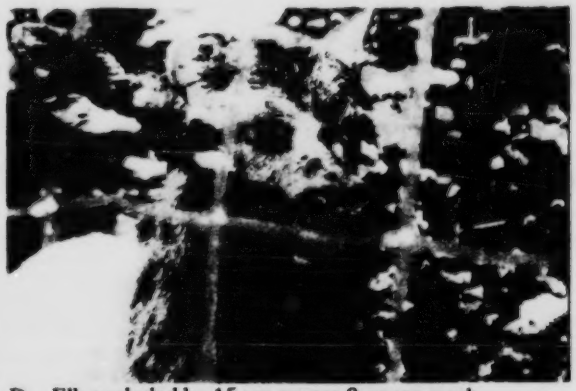
East of BNP, an additional zone was identified: TCH EAST from km 0 at the East Gate to km - 35.2 at Seebee. TCH EAST includes a portion of the BVER from km 0 to km -4.0 (TCH EAST-BVER). During 1983-87, TCH EAST was a four-lane divided freeway with an average speed limit of 110 km/hour and traffic volumes equal to or greater than TCH I. TCH EAST is managed by the AB government and is bordered by private and public ownership lands. It remained unaltered during the reconstruction of TCH I and TCH II.

B. 2.4 m high ungulate-proof fencing, normal installation. Photograph by John G. Woods

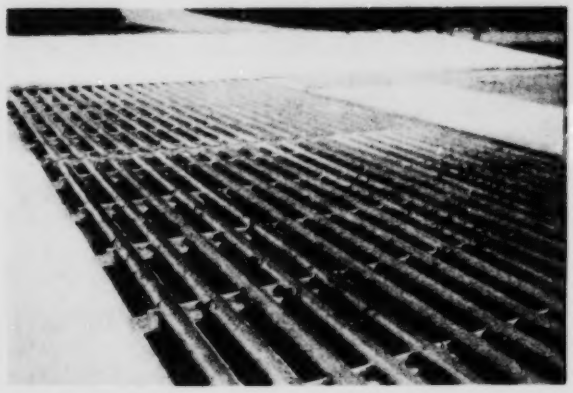
A woven-wire fence with 15 cm square 9 gauge mesh was installed along both sides of the reconstructed highway in BNP. With the exception of short sections of lowered fence height in steep situations in the Vermilion Lakes area, the entire fence was 2.4 m high. The bottom wire of the fence followed landscape irregularities within 15 cm. Pipe-style Texas gates (cattleguards) 5 m wide were installed at all intersections.

The fence crossed the CPR at 1 location. To discourage ungulates from walking into the fenced zone, heavy plastic sheeting was placed between the rails and between the outer edges of the rails and the fence.

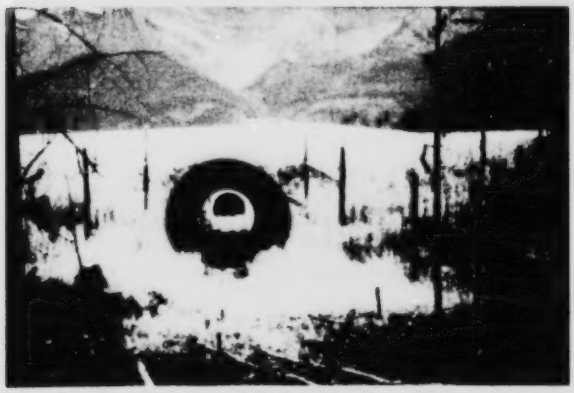
C. 2.4 m high ungulate-proof fencing, metal posts in rock cut area. Photograph by John G. Woods



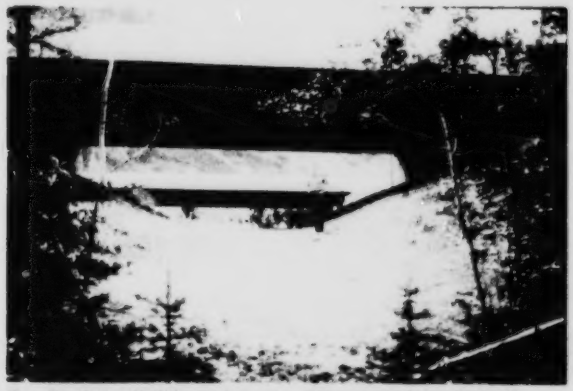
D. Elk excluded by 15 cm square 9 gauge mesh. Photograph by John G. Woods



E. Texas gate. Photograph by John G. Woods



F. Morrison Coulee wildlife underpass. Photograph by John G. Woods



G. Duthil wildlife underpass. Photograph by John G. Woods

H. East Gate wildlife underpass. This was the only offset underpass in the project. Photograph by John G. Woods

I. Canadian Pacific Railway bridge in TCH II being used as an overpass by bull elk. Photograph by John G. Woods

J. One-way gate. Photograph by John G.Woods

Although the ends of the fence were terminated as close as possible to the road, there were no barriers on the highway surface to prevent animals from walking into the fenced zone at the 2 ends-of-fence. In TCH I, the fence was in place by December 1984 but was not completely installed in TCH II until September 1987.

Structures of varying design were available to ungulates to traverse the fence barrier at twelve locations (Figure 1). These included 8 wildlife underpass locations built specifically to allow animal crossings, 3 routes beneath structures built primarily as watercourse bridges, and a railway overpass not intended for animal use. Animals using crossings passed under the highway for a distance of at least 30 m.

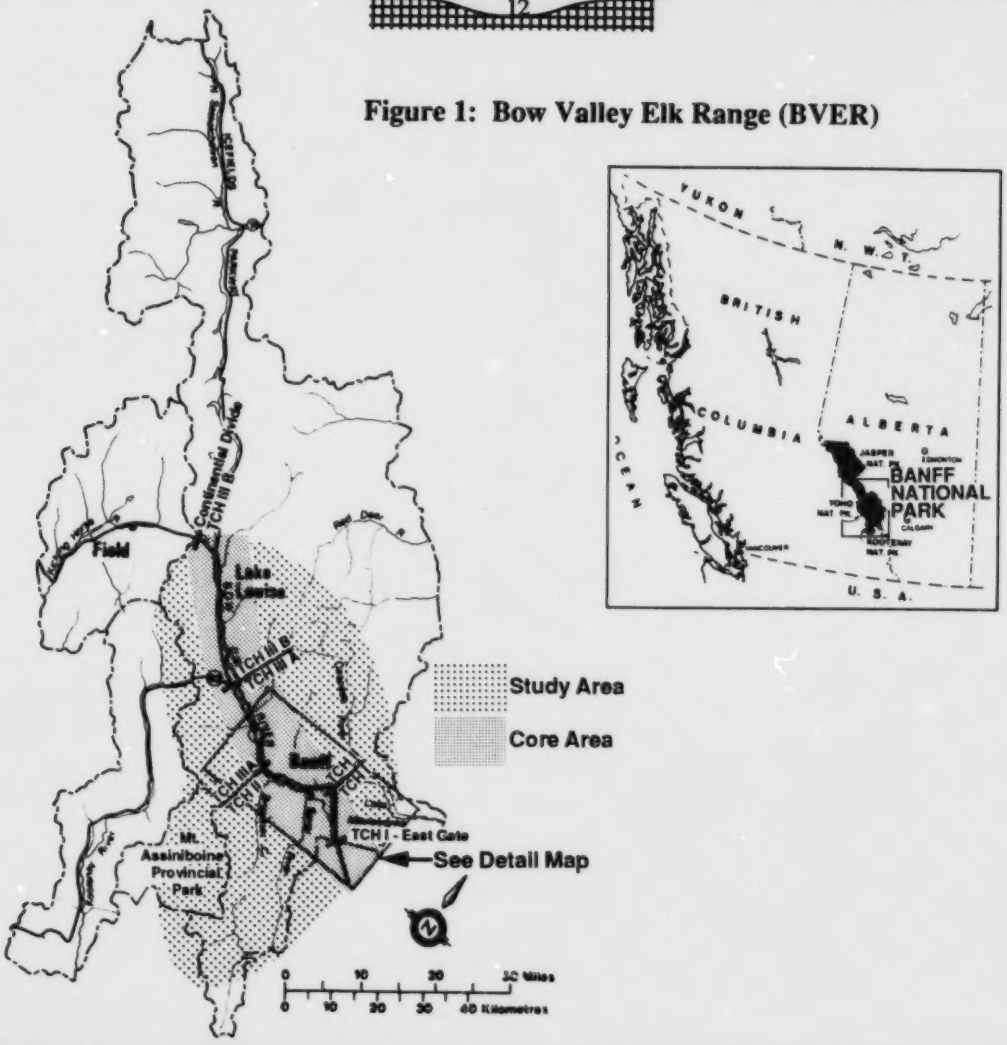
Seven wildlife underpasses (East Gate, Duthil, Powerhouse, Grasslands, Vermilion, Edith, and Healy) were constructed by spanning depressions with concrete and steel bridges. Although the openings beneath these bridges were approximately 15 m wide, the side slopes reduced potential level tread width to 4-5 m. Each had a clearance of approximately 4 m from the center tread to the bottom of the bridge. One wildlife underpass (Morrison Coulee) was through a 4.27 m diameter metal culvert with a dirt floor and similar tread clearances to the concrete and steel underpasses.

Watercourse bridges on the TCH also created 3 wildlife underpasses. These included a 1.5 m wide pathway beside a creek (Carrot Creek Bridge), a 38 m wide dry spillway (Cascade River Spillway), and a 86 m wide riverside area (Five Mile Bridge).

At the fenced intersection of Banff Avenue and the TCH, a CPR bridge created an overpass which although not intended as an animal route, was used by ungulates as a crossing. The bridge paralleled the highway and spanned fence segments around the intersection by passing 7 m above a secondary road. The 15 x 115 m deck included an active railway line and a 3.5 m gravel tread installed for future twin-tracking.

A number of swing gates were included in the fence to allow access to restricted roads and to facilitate active animal removal by park staff. Several one-way gates similar in concept to those described by Reed et al. (1974) were included in the fence to allow trapped animals to exit the fenced corridor without human assistance.

Figure 1: Bow Valley Elk Range (BVER)



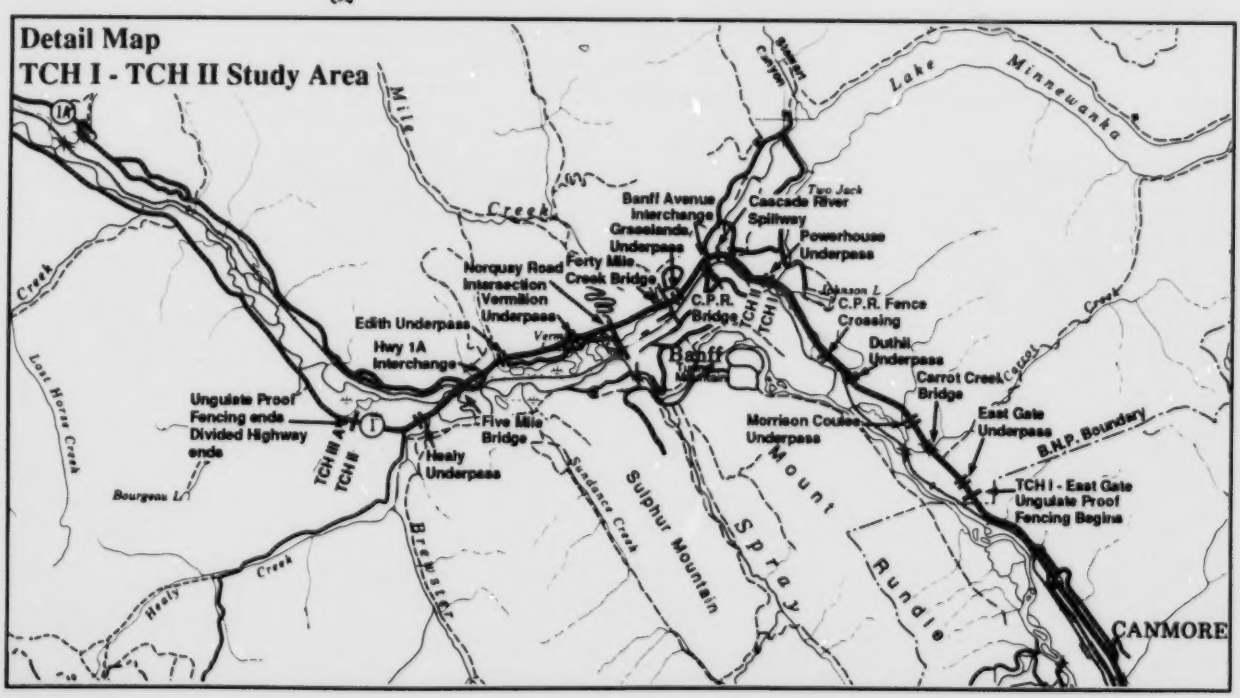
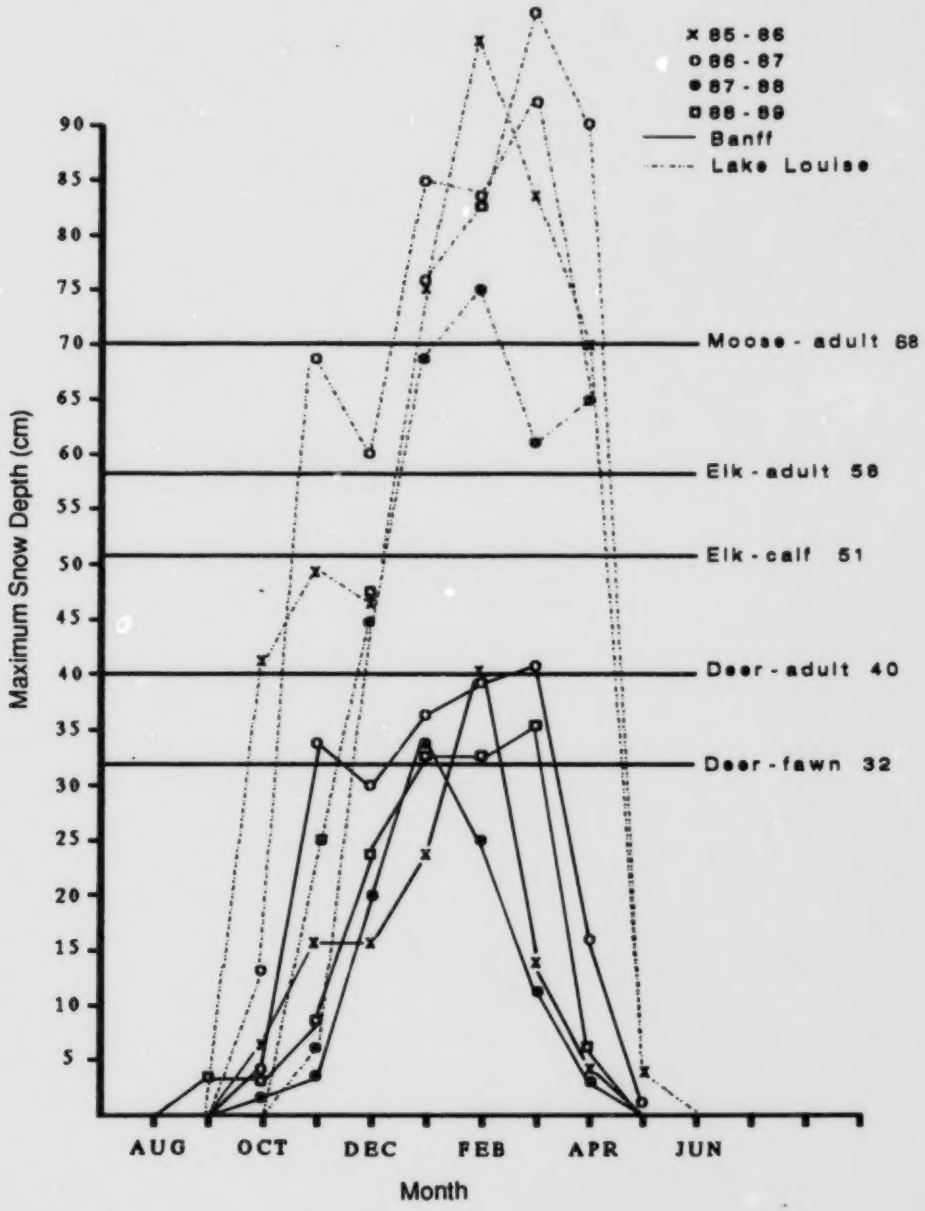


Figure 2: Maximum Monthly snow depths at Banff townsite and Lake Louise townsite, 1985-89. Horizontal lines represent snow depths which impede ungulate mobility (adapted from Trottier et. al. 1983). Data presented in Appendix 2 and 4



3.0 METHODS, SAMPLES, AND DEFINITIONS

3.1 MOVEMENT BEHAVIOR

3.1.1 Elk Radio Telemetry

Radio telemetry allowed continuous tracking of individual movement behavior independent of visual observability. Free ranging elk were immobilized and fitted with either radio collars or solar powered ear-tag transmitters. During the study period, 64 elk including 38 adult females, 18 adult males, and 8 calves were successfully immobilized and fitted with transmitters (Woods 1986a,1988).

K. Park warden placing radio collar on an adult female elk. Note numbered tag on the side of the collar. Photograph by John G. Woods

A numbered tag was riveted onto the side of each collar to allow visual identification of individuals. The collar transmitters had estimated battery life of 48 months and had mortality sensors which were triggered by 3 hours of inactivity. A small metal numbered ear-tag was fixed onto the alternate ear of all elk fitted with ear tag transmitters. Only elk in the BVER within BNP were fitted with radio transmitters. The distribution of collars by sex and area approximated the winter distribution of elk and the winter sex ratio estimated by the park warden service (R. Kunelius, CPS, pers. commun.).

Immobilization of adult females and males was not selective for age classes >00 with the following exceptions: only 1 female was collared from any group at a time; 3 females collared in previous studies were re-collared (2 from BNP and 1 originally collared in Kootenay National Park), and 2 age 01 males were selectively immobilized and fitted with ear-tag transmitters. All elk were immobilized during the winter period (November-May) except for 2 adult male and 1 adult female collared in August. In 1987, an effort was made to selectively immobilize the calves of collared females. Calves previously fitted with ear-tag transmitters were recaptured if possible and fitted with a radio collar when they graduated to age 01.

Mapped ground locations within the BVER were obtained at intervals of 7 days or less during the daylight hours. In a trial to compare night-time to daytime relocation schedules, elk were found to move farther at night but to have similar movement patterns night and day (Bottini et al. 1986). Merrill et al. (1987) discussed daytime versus 24 hour elk locations and came to similar conclusions.

The road network within the BVER usually allowed very close approach to the animal and multiple bearings. Three or more compass bearings were taken from mobile ground receivers and plotted on standard park ecosite maps (scale 1:50,000) in the field. If the plotted polygon was greater than 200 m in any dimension, additional bearings were made to improve precision. Radio signal "bounce" was frequently encountered but these signals became obvious when plotted in the field. Field trials in the TCH II area suggested an accuracy of approximately 200 m. The actual error of each mapped ground observation was not measured but believed to be a complex function of position in the valley and observer. When new personnel came to the study, they worked with experienced personnel and field locations were tested.

Starting in September 1986, additional elk locations within the BVER were obtained at intervals of 3 days or less per week to determine which side of the TCH an animal was on. These "sidecheck" locations determined accurately whether the animal was north or south of the TCH corridor and the status of the mortality sensor. When it was determined that an elk had crossed the TCH corridor, a mapped location was obtained.

When engaged in either sidecheck or mapped ground location surveys, the researchers scanned all deployed radio frequencies whether or not a particular animal was believed to be in or out of the BVER.

At monthly intervals in 1986 and biweekly intervals thereafter, mapped aerial locations were obtained for elk which had moved outside the BVER . Mapped aerial locations were determined from multiple passes with a twin antennae system mounted on a helicopter. In most cases the animal was either seen, or a had an estimated position directly below the helicopter. In consultation with the pilot, the observer plotted the animal's position on ecosite maps and verified the animal's elevation with the helicopter altimeter.

All mapped locations were entered onto standard data sheets in the field and transferred to a micro-computer database including fields for animal identification, date, time, U.T.M., elevation, ecosite as indicated on ecosite maps, and incidental observations on group size and composition, behavior, and antler condition. In addition to new radio locations obtained in this study, the field notebooks from a previous radio tracking study by the park warden service (Jacobson 1981) were analyzed and placed in the telemetry database (P. Jacobson, CPS, pers. commun.).

3.1.2 TRACK COUNTS

In parallel studies, the park warden service recorded individual underpass use as measured by track counts across sand pads installed beneath several TCH I and TCH II underpasses. These pads were examined once every other day and then raked smooth. Results from TCH I have been reported on by Browne (1986) and Waters (1988). These studies also reported intrusions into the fenced zones.

3.1.3 INCIDENTAL OBSERVATIONS

In addition to survey observations, elk and other ungulates were opportunistically observed along the TCH and CPR corridors and in the vicinity of underpasses. Detailed notes were made on these occasions.

3.2 MORPHOLOGICAL CHARACTERISTICS

Morphological data were obtained on an opportunistic basis from necropsies of elk, deer, and moose salvaged during the study. The park warden service examined bighorn sheep carcasses.

Age was assessed by tooth eruption patterns for age class 00 and 01 animals (Larson and Taber 1980). Age class animals >01 were assessed from cementum analysis of the central lower incisor (I1) or the upper canine (C1) if available (analyzed by Matson's Laboratory, Milltown, Montana).

Fat condition was assessed by kidney fat indices, rump fat, and bone marrow. Skeletal size was assessed by measurement of total jaw length and dry antler weight. Body weights were obtained by weighing the entire carcass less any blood lost in transit.

3.3 ELK POPULATION STRUCTURE, SIZE, AND MODELING

Classified elk counts were made immediately after the rut each autumn (mid October through early November) and during the green-up (mid April through early May) from autumn 1985 through spring 1989. During each classified count, the study team travelled the entire road network (approximately 200 km of roads) within the BVER each morning or evening within 2 hours after dawn or before sunset. This was repeated for up to 5 days and the maximum number of elk seen without apparent duplication was recorded for each area. Each elk was observed through a 20x spotting scope by an experienced observer and classified as either age 00, age 01 male (with spike antlers), age >01 males (with branched antlers), or age >00 female.

Since collared elk were not used to locate elk groups during classified counts, the presence or absence of collared elk allowed a Peterson's mark-recapture estimate of population size. Only elk known to be within the BVER were used as the potential marked animals.

Population size also was reconstructed using mortality rates of radio collared elk killed on the TCH and the total number of TCH road-killed elk located.

Total counts were made by the park warden service using standardized methodology (Kunelius 1985). On up to 3 occasions per year, the entire BVER was surveyed by 3 observers in a low flying helicopter flying a predetermined flight path which covered the entire BVER from Canmore to Lake Louise. The flights were scheduled to complete the counts on 3 consecutive mornings covering approximately one-third of the BVER per flight. The resulting count gave a minimum number of elk within the BVER. In the spring of 1988, the aerial count was replicated 3 times. The presence or absence of collars was not used to estimate observability because the collars were not easily observed from the air.

A mathematical model of the elk population in the BVER was developed as a working tool to consolidate population data and to allow the examination of alternative management strategies. This model is logistical in form and uses an equation adapted from Houston (1982) to relate the mid-winter elk population at time t with the calf recruitment to mid-winter at time t+1:

$$y=0.624-0.164x$$

where y is the calf:cow ratio at time t+1
x is the total elk population (/1000) at time t.

This function was re-scaled for the BVER assuming a candidate ecological carrying capacity (K_1) in the absence of man-caused mortalities. A real K_1 for the BVER is unknown and will likely change with time. The candidate K_1 (4,300) is a trial figure within the range for "very high" potential elk carrying capacities (9.9 to 13.0 elk /km^2 /year) as defined by Demarchi et al. (1983) for comparable BC elk ranges.

No direct count estimates of population structure or size were made for bighorn sheep, mule deer, or white-tailed deer. Moose were very rarely observed during the study.

3.4 PREGNANCY RATES

Pregnancy rates were determined *in utero* for age class >00 females during the period December through May. Additional information on recruitment was obtained from classified elk counts (see 3.3)

3.5 UNGULATE MORTALITY

Radio collared elk were used as an independent source of mortality data. Whenever a transmitter was detected on mortality mode, the situation was investigated as soon as possible and the cause of death determined. If the precise cause of death could not be determined, the cause was classified as either natural or unnatural (man-caused). In February 1987, the park warden service commenced a preliminary timber wolf radio tracking study in the BVER. Wolves followed as part of that study provided additional information. To be classified as a wolf kill, evidence must have been found which indicated that the animal had been killed by the wolves (eg. struggle marks in the snow).

Most ungulate mortalities within BNP on the highway were located by the park warden service and removed from the accident site. Animals hit on the highway but dying out of sight were located coincidentally to other work or by mortality mode transmissions from radio collared elk. Constant patrolling by the warden service is thought to have located the majority of road-kills (see section 4.1.1). During the first year of the study, all mortality locations were staked and location examined by the research team. Location coordinates were calculated to the nearest 0.1 km using standard 1:50,000 park ecosite maps. The species, sex, and age of the majority of animals was verified by the researchers. Standard CPS computer file mortality forms completed by the wardens were examined and a more detailed computer file research file established for each animal.

L. Park warden removing a road-killed elk from the Trans-Canada Highway. Photograph by John G. Woods

Ungulate and carnivore mortalities were recorded east of the park along the TCH to Highway 40 (TCH EAST). Road-kills within this zone were reported to the researchers through the cooperation of several agencies including the Alberta Department of Highways (Canmore), the Royal Canadian Mounted Police (Banff and Canmore detachments), Bow Valley Provincial Park, and Alberta Fish and Wildlife (Canmore office). After a kill was reported, it was examined by the researchers and included in the research file.

Kills along the railway were much more difficult to locate than highway kills because much of the railway is not observable from park roads. Although some ungulate-train collisions were reported by CPR staff, most were opportunistically reported by park wardens and the cooperating agencies listed in 1.3.

Starting in March 1987, systematic helicopter surveys of the entire CPR line through the BVER were made on or about the 1st and 15th of each month. Flights were made at an altitude of 100 m and a speed of 100 to 140 km/hr. An observer beside the pilot and another behind the front observer, examined the entire line to a distance of approximately 50 m on each side. Most kills were quickly located by the presence of scavenging birds, principally ravens. Whenever possible, the helicopter landed near the kill site and as much biological information as possible was salvaged. Data were included in the research file.

3.6 PARASITES

This study continued the parasitological collections begun in 1984 by the park warden service. When the condition of a salvaged carcass allowed, the lungs and liver were re-

moved and sent to Alberta Wildlife in Edmonton, AB. where Dr. Margo Pybus examined them for the presence of giant liver fluke (*Fascioloides magna*), lung worms (*Dictyocaulus viviparus*) and hydatid cysts (*Echinococcus granulous*). All liver samples were thinly sectioned and the major lung passageways were cut open. Although no specific effort was made to locate external parasites, incidental observations of winter tick (*Dermacentor albipictus*) infestations were recorded in the research file.

3.7 FORAGE QUALITY AND COMPOSITION

Fresh elk feces were collected at 2 to 4 week intervals throughout the study period. Each collection consisted of at least 3 pellets from 15 pellet groupings.

For fragment analysis fecal samples were air dried and sent to the Composition Laboratory, University of Colorado, Fort Collins, Colorado. Estimates of dry weight percentages were developed using the technique described by Sparks and Malechek (1968). Each field sample was sub-sampled by making 3-5 slides and reading the relative frequency of occurrence for each identifiable plant fragment in 20 fields per slide. These frequencies were then converted to relative dry weights and between sub-sample means determined.

For fecal protein analysis, fecal samples were fresh frozen and analyzed for total nitrogen at Norwest Laboratories, Edmonton, AB and Crossfield Laboratories, Crossfield, AB.

During 1988, fresh forage samples were collected for mixed grasses (Gramineae), willows (*Salix* spp.), and buffaloberry (*Shepherdia canadensis*). Samples were obtained by locating groups of feeding elk and then collecting material in that site or from a nearby site. Each sample consisted of 50 sub-samples picked by hand to simulate an elk "bite". For grasses, cured stems and leaves were picked only if green material was not available. For shrubs, current year stem growth was picked only if leaves were not available. These samples were fresh frozen and sent to Crossfield Laboratories, Crossfield, AB for sequential fiber analysis as described by Robbins and Moen (1975) and for total nitrogen.

Rumen and rectal content samples were collected and dried for elk, deer, and moose on an opportunistic basis. These samples have not been analyzed.

3.8 PARK FILES AND DATA STORAGE

This study reviewed all files on elk maintained by the Senior Wildlife Warden in the BNP Warden Office. Records of road-kills from 1970 through 1984 were reviewed and corrected by R. Kunelius (CPS, pers. commun., 1988).

3.9 STATISTICAL ANALYSIS AND DATA STORAGE

Standard parametric and nonparametric tests were performed on a micro-computer using Statgraphics software (Statistical Graphics Corporation, 1988) run on an MS-DOS compatible micro-computer. Morphological data were analyzed with parametric techniques and behavioral data with nonparametric methods. Behavioral changes expressed in numeric fashion before and after fencing TCH II were analyzed using Wilcoxon paired samples only. Paired ordinal data were analyzed using McNemar's technique (Zar 1974). As suggested by Krebs (1989), Chi^2 analyses were restricted to cases where the minimum expected frequency was > 3. Confidence intervals for classified elk counts were calculated using the formula presented by Sinclair and Grimsdell (1983). For all tests, the null hypothesis was rejected if $P < 0.05$.

All radio location, morphological, and mortality data were stored in ASCII code compatible form on a micro-computer. McPaal software (Stuwe and Blohowiak 1985) were used to generate minimum convex polygons from location data.

All data gathered during this study have been placed on file at the park warden office in Banff and in the Western Regional Office Library, CPS, Calgary in printed summaries and micro-computer accessible form.

3.10 DEFINITIONS

Age class 00: an ungulate in the first year of its life during the period May 1 to April 30; necropsy class 00 were evaluated on the basis of tooth replacement; field classifications for elk were evaluated on the basis of size and head configuration (no antlers, stubby noses, association with adult females).

Age class 01 males: an ungulate in the second year of its life; necropsy class 01 were evaluated on the basis of tooth replacement; field classifications for yearling elk males were based on the presence of unbranched (1point) or forked (2 points) antlers (age class 01 females could not be distinguished reliably from older females in the field).

Age class >01 males: an ungulate in the third or more year of its life; necropsy class 02 elk were evaluated on the basis of tooth replacement or cementum analysis; class 02 deer and moose were evaluated on the basis of cementum analysis; field classifications for male elk were based on the presence of multi-branched antlers, size, and coat colour.

Annual familiar area (AFA): the minimum convex polygon (see Stuwe and Blohowiak 1985) formed using all mapped locations from Feb 1 to Feb 1 (the first collared elk sample was available for tracking Feb 1, 1986), units km^2.

Antler weight: the weight expressed in kg of a single dry antler weighed at least 6 months after collection (see Clutton-Brock 1982); Flook (1967) used wet, total antler weights (both sides). To convert Flook's antler data into estimated dry weights his figures were multiplied by 0.5 (to give a single side estimate) and then by 0.93 (to correct for the average water loss from wet antlers observed in this study).

Autumn migration: a return movement lasting at least 15 days by an animal which has already performed a complete summer migration and which takes the animal back to its summer range for a portion of September, October, November, or December.

Biological year: May 1st of any year to April 30th the following year; during any biological year, no animal changes age classes; all animals have an assumed birthday of May 1st. Note that in many other studies the biological year is from June 1st to the following May 31st, however, in the BVER, use of this date would result in confusion in the 00 age class since many young ungulates are born in late May. This biological year was suggested by R. Kunelius (CPS, pers. commun.) and is used for all warden reports in BNP.

Body weight: the weight of the whole animal including antlers in males expressed in kg; Flook (1967) used the same method for females but subtracted the wet antler weight for antler bearing males.

BVER: the area of the Bow River valley below 1700 m in elevation between Canmore and the summit of Kicking Horse Pass.

Calendar year: January 1st of any year to December 31st of the same year; note that any animal older than 00 would change age during a calendar year since most ungulate births occur in late May and early June.

Classified count: direct ground counts of age class 00, age class >00 females, age class 01 males, and age class >01 male elk made by research personnel or Senior Wildlife Wardens from the ground by viewing each elk in profile through a 20x spotting scope or its equivalent; Flook (1967) used a similar technique but with a greater variety of warden personnel; classified count results are expressed in terms of per 100 adult females.

CPR East: CPR parallel to TCH East (East Gate to Hwy 40).

CPR East-BVE: CPR parallel to TCH East-BVE (East Gate to Canmore).

CPR I: CPR parallel to TCH I (East Gate to Powerhouse underpass).

CPR II: CPR parallel to TCH II (Powerhouse underpass to 1.6 km west of Sunshine interchange).

CPR IIIA: CPR parallel to TCH IIIA (1.6 km west of Sunshine interchange to Castle Junction).

CPR IIIB: CPR parallel to TCH IIIB (Castle Junction to summit of Kicking Horse Pass).

Crude protein: an estimate of forage or fecal protein obtained by multiplying the crude nitrogen in a sample by 6.25.

Ecological carrying capacity (K_t): a stable equilibrium in a population resulting from interaction between ungulates with vegetation; as pointed out by Houston (1982), this is not to be confused with K_e, the economic carrying capacity, the population at which some human-oriented objective is maximized (eg. sport hunting).

Elk year: the total number of days a radio collared elk was tracked within a given time period divided by 365.

Familiar area (FA): the minimum convex polygon (see Stuwe and Blohowiak 1985) formed using all mapped locations for an animal over a specified time period, units km^2; FA-BVER :that portion of an animal's familiar area within the BVER, units km^2; FA-TCH: the cord distance between the 2 points on TCH defined by the intersection of the TCH with an animal's FA, units km.

Fecal fragment analysis: the microscopic technique of determining the identity of undigested forage fragments found in animal feces.

Fecal nitrogen (FN): the percent nitrogen in fresh fecal material; FN can be converted to an estimate of fecal protein by multiplying by 6.25.

Fencing effectiveness: the observed reduction in road-kills after fencing; for TCH I, the expected road-kills without fencing was calculated by comparison with TCH III and the historic relationship between TCH I and TCH III, for example, if TCH III had 23 elk kills in biological year 1988-9 and the historic elk road-kill relationship between TCH I and III was 61:39, then the the expected kills in TCH I was 36 (61/39x23); for TCH II, fencing effectiveness was calculated directly before and after fencing during the years 1985-89.

Finite rate of population increase (FRI): the ratio N_{t+1}/N_t where N is the estimated population at time t.

Highway crossing index (HCI): the total number of highway corridor crossings divided by the total number of daily sidechecks.

Historic road-kill ratios (1977-82): elk, TCH I:II:III=48:22:31; mule deer, TCHI:II:III= 29:38:34; white-tailed deer, TCH I:II:III= 38:35:27; bighorn sheep, TCH I:II:III=0:100:0; moose, TCH I:II:III=0:13:87. Chi^2 tests of average (1977-82) ratio models compared to yearly data: elk model fitted projections for all

TCH I: III comparisons and 5 of 6 TCH II:III comparisons (in 1981 there was a significant increase in TCH II relative to TCH III (P=0.007); mule deer fitted projections for all cases; white-tailed deer data insufficient to test except for TCH II:III comparison in 1980, which fitted the model.

Instantaneous rate of population increase (IRI): the natural log of the ratio N_{t+1}/Nt where N is the estimate population at time t.

Jaw length: the cord distance measured in mm from the anterior portion of the first incisor socket to the posterior angle of the mandible.

Kidney fat index (KFI): the total weight of 1 kidney and perinephric fat without trimming divided by the weight of the kidney alone (see Mitchell et al. 1976); this index has a range of 1 to 5 with 1 representing no fat, and 5 extremely fat; note that Flook (1967) used a trimmed fat method (Riney, 1955), so that the results are not directly comparable.

Mapped aerial radio location: a radio location determined from multiple passes with a twin antennae system mounted on a helicopter.

Mapped ground radio location: a radio location determined using a hand-held antenna to obtain 3 or more bearings which formed a polygon with a maximum diameter of 200 m; or, a location based on the sighting of an identifiable animal.

Parasite prevalence: the percentage of animals in a population with a particular parasite.

Percent locations north of the TCH: the number of sidecheck locations for an individual north of the TCH divided by the total number of sidechecks for that individual.

Population estimate based on direct counts: the actual number of elk observed by park wardens on standardized route helicopter surveys conducted in late April or early May within the BVER; all available terrain was covered; before 1985, no BVER elk population estimates included the area between East Gate and Canmore.

Population estimate based on mark-recapture: An estimate of the late April or early May population size within the BVER made during spring classified elk counts based on a modified Peterson index (see Washburn and Gillis 1987):

$$N=(M+1)(R+1)/(C+1)$$

where N is the estimated population size
M is the number of collared elk within the BVER during the census
C is the number of collared elk observed
R is the the total number of elk observed.

Collared adult females were used to estimate adult female, calf, and spike male populations because calves and spike bulls were usually observed in mixed groups with adult females and because there was no apparent difference in observability between these classes. This estimate was then added to a separate estimate for adult male elk based on collared males aged >01.

Population estimate based on mortality reconstruction: an estimate of the late April or early May population size within the BVER reconstructed from calculated road-kill mortality rates estimated from collared elk and the known number of road-kills.

Road-kill: an animal which was either killed outright or injured beyond recovery after colliding with an automobile.

Rutting migration: a return movement by a bull elk to a specific area during August and September which spans the period September 15 - 25.

Sequential fiber analysis: the chemical analysis of a forage or fecal sample resulting in the sequential determination of neutral detergent fiber (NFD), acid detergent fiber (AFD), and lignin extract.

Sidechecks: a radio location from the TCH which accurately determined whether an animal was north or south of the highway but which was not necessarily mapped.

Summer migration: a return movement lasting at least 15 days from 1 area to another and back again which starts before September 1st and ends before December 1st.

Summer visit: a return movement lasting less than 15 days during the summer migration period from the summer range back to the winter range.

Summer departure date: the last day of radio contact within the Bow Valley for an animal which subsequently was known to perform a summer migration. The date is expressed in terms of day of the year (eg. January 1st = day 1, December 31st = day 365).

Summer return date: the first day of radio contact within the Bow Valley for an animal which had performed a summer migration. The date is expressed in terms of day of the year (eg. January 1st = day 1, December 31st = day 365).

TCH East: TCH East Gate to Hwy 40 (km 0 to - 35.2).

TCH East-BVE: TCH East Gate to Canmore (km 0 to -3.9).

TCH I: TCH East Gate to Powerhouse underpass (km 0 to 11.0).

TCH II: TCH Powerhouse underpass to 1.6 km west of Sunshine interchange (km 11.0 to 26.1).

TCH IIIA: TCH 1.6 km west of Sunshine interchange to Castle Junction (km 26.1 to 46.0).

TCH IIIB: TCH Castle Junction to summit of Kicking Horse Pass (km 46.0 to 80.2).

TRAIN-KILL: an animal which was either killed outright or injured beyond recovery after being hit by a train.

Ungulate carrying capacity: as defined by Demarchi et al. (1983) the number of animals a given range can support on a year round basis; units are animals per km^2 per year.

Winter migration: a return movement lasting at least 15 days from 1 area to another and back again which starts after September 1st and ends before May 1st the following year.

Winter visit: a return movement lasting less than 15 days during the winter migration period from the summer range back to the winter range.

Winter departure date: the last day of radio contact within the Bow Valley for an animal which subsequently was known to perform a winter migration. The date is expressed in terms of day of the year (eg. January 1st = day 1, December 31st = day 365).

Winter return date: the first day of radio contact within the Bow Valley for an animal which had performed a winter migration. The date is expressed in terms of day of the year (eg. January 1st = day 1, December 31st = day 365).

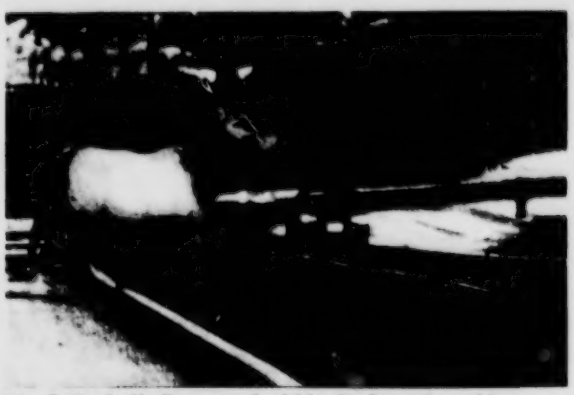
4.0 EFFECTIVENESS OF THE FENCE

4.1 ROAD-KILLS ON THE TWINNED HIGHWAY WITH FENCING

4.1.1 RESULTS

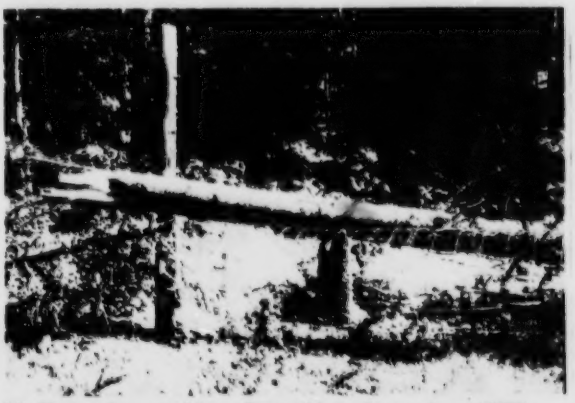
During the 19 calendar years, 1970-88, 1,469 ungulates were reported as killed on the TCH in the park (Appendix 9). During the 4 biological years (1985-89) of this study, 645 ungulates were reported as killed by man-related causes in the BVER (Table 1). Of this total, 373 (64% elk) were reported as TCH road-kills within the park. Of 5 radio collared elk killed on the TCH during the study, 1 (20%) was hit on the highway but died out of sight in heavy timber and probably would not have been located without radio telemetry.

In TCH I, ungulate road-kills were reduced by an estimated 94% after fencing during the biological years 1985-89 (Table 2). In TCH II, ungulate road-kills were reduced by 97% after fencing during the biological years 1987-89.



M. Spike bull elk trapped within the fenced corridor. Photograph by Doug Leighton.

Despite fencing, warden reports document 861 ungulates (primarily elk) within the fenced TCH I zone during the period June 1983 to December 1987 (Waters 1988). Most of these intrusions occurred during construction. Few deer and no moose were seen within the fenced corridor. Open ends of the fence accounted for approximately 90% of all the intrusions. Other means of entry included the CPR fence crossing, TCH Texas gates, open swing gates, and damaged fences. Only 2 elk were known to have crossed TCH Texas gates and none to have jumped the fence. In contrast to elk outside the fence, elk trapped within the corridor were typically highly excited and crisscrossed the highway in an apparent effort to escape.



N. Fence damaged by a forest blow down, June 1987. Photograph by John G. Woods

A total of 370 elk were observed by park wardens exiting the fenced corridor in TCH I through one-way gates (Waters 1988). Some of these animals were herded through the gates by park wardens. At the East Gate end-of-fence, several elk regularly entered the fenced corridor by walking on the highway pavement and left via a nearby one-way gate. Although elk of all ages and both sexes used one-way gates, some elk refused to use them, even if strenuously herded by park wardens. In these cases, the nearest swing gate was opened and the animals gently herded out. In 1 instance, a bull elk refused to move and it was necessary to open an

adjacent seam in the fence to allow him to exit. During the period June 1983 to December 1987, park wardens spent at least 232 person-hours removing elk from the fenced project.

During all years of the study, the road-kill distribution was significantly altered compared to the pre-construction distribution of kills relative to TCH III outside the construction zone (Table 3). In TCH I, there was a significant reduction in the numbers of elk, mule deer, and white-tailed deer killed within the fenced zone during all years. In TCH II, there was a significant reduction in road-kills of elk, mule deer, and white-tailed deer in 1987-88 after fencing. No sheep or moose were killed within the fence.

Twenty-eight proven or suspected cases of predation on ungulates beside the fence were recorded during 1985-89. These included 3 elk, 2 mule deer, and 23 bighorn sheep. Timber wolves were implicated in the elk kills and coyotes in the deer and bighorn sheep kills (Banff warden serv. unpubl. data).

4.1.2 DISCUSSION

The fencing effectiveness rates observed on TCH I and II during this study (94% and 97%) are exceptionally high. Experience in other areas has shown variable success with fencing. Feldhamer et al. (1986) described an "ungulate-proof" fence system which did not decrease white-tailed deer kills. Deer continued to gain access to the fenced corridor at unprotected intersections, under the fence at terrain irregularities, through the wire mesh, and through man-made holes in the fence. Other reports of fencing success range from 60 to 93% reductions in road-kills (Reed et al. 1982, Ludwig and Bremicker 1981, Clayton and Smith 1989).

The fencing success along TCH I and II appears to be the result of several factors. The 2.4 m height effectively made the fence insurmountable by the 5 species involved. The design clearance for the bottom wire above ground and the careful attention to ground irregularities prevented most animals from crawling beneath the fence. Furthermore, all intersections were protected by Texas gates (unlike the project described by Feldhamer et al. 1986).

Experience during and after construction illustrated the vulnerability of the ends-of-fence. The obvious solution of placing Texas gates across the highway at these points initially was not considered acceptable on this high traffic, high speed roadway. However, due to the failure of all alternative barriers, a high speed Texas gate is now being designed (B. Leeson, CPS, pers. commun., March 1990).

Bellis and Graves (1971), in a study of of fencing within a white-tailed deer range in Pennsylvania, noted that fencing short sections of highway adjacent to high crossing areas might simply deflect deer around the ends-of-fence and funnel animals into the fenced zone. During construction of TCH I, numerous "ends-of-fence" between fence segments resulted in many intrusions. This problem was reduced by progressive fence construction along both sides of the highway from east to west in TCH II.

The East Gate end-of-fence was a particular problem. Here the fence terminated at the park boundary in an more or less level HD1 ecosite with high year-round attractiveness to elk and deer. The fence came to an end against a concrete median at right angles to the edge of the highway along a rock and rubble shoulder. Elk frequented the area and often gained access to the fenced corridor by walking on the highway pavement from outside the park. B. Leeson (CPS, pers. commun.) described the

determination of these elk to enter via this point: "They had to walk on the highway, perhaps sometimes in the presence of vehicles, pass close to a manned entrance point and over the underpass bridge to get to the foraging area which attracted them. We had concrete barriers, rock rubble, and eventually, a defector fence."

The majority of all intrusions in the project come from this single source. In contrast, although the permanent end-of-fence at the west end of TCH II is also in high use VL3 ecosite, the terrain on the south side of the highway is very steep and a double set of wing fences were specially constructed to intersect the highway at acute angles to lead animals away from the opening to the fenced corridor. Although animals could gain access by walking directly down the pavement, few if any have, and this end-of-fence has proven very successful.

The fence crossing of the CPR in the TCH I zone also proved problematic. Here, instead of standard metal Texas gates, a variety of slippery plastic or metal sheets have been tried between the rails and at the approaches to the rails. These efforts have met with mixed success. Some have been ripped out by low hanging objects on trains. All designs have failed when drifted in by crusty snow. Several elk learned to walk directly on the plastic. One deer learned the locations of small openings just big enough for its feet (B. Leeson, CPS, pers. commun.).

Gates also met with mixed success. Some elk learned to use one-way gates; others refused to use them, even when herded towards them by park wardens. Of particular importance in one-way gate design was that they were well maintained and did not stick in the open position once used. In cases where animals would not use one-way gates, the provision of conventional swing gates was essential to the successful active herding of animals out of the fenced zone. These swing gates became liabilities when unintentionally left open.

Accidental breaks in the fence barrier caused by motor vehicle accidents and wind thrown trees were quickly found by elk and used to access the fenced corridor. Prompt attention to fence repair and maintenance of all ancillary structures was an essential ingredient in the fencing success.

Active removal of intruding ungulates by the warden service was probably an important factor in the exceptionally high success rate of the project. The observed effectiveness of fencing would probably have been substantially lower without the constant surveillance and active removal by park wardens.

Although the fence effectively reduced bighorn sheep road-kills in the TCH II sheep range, a park warden service study has documented a considerable number of apparent coyote-killed sheep against the fence (Banff warden serv. unpubl. data). In this area, the fence excluded bighorn sheep access from some of their traditional escape terrain on the cliffs bordering the highway. Geist (1971) noted that "The major sheep predator appears to be the wolf. Coyotes...may take an occasional sick or incapacitated sheep,...". If the fence is facilitating coyote predation on bighorn sheep and increasing their natural predation rate on bighorns, then the management hypothesis of reducing road-kills without disturbing the natural mortality rates has not been achieved for bighorn sheep. The problem is under active evaluation by the park warden service (R. Kunelius, CPS, pers. commun.).

During construction of the road-cuts through their escape terrain, the bighorn sheep seemed oblivious to construction. During this time they were frequently seen bedded beside active

drilling rigs and their backs were frequently covered by rock dust. Morgantini (University of Alberta, pers. commun.) has noted similar tolerance to construction activities at well sites on the East Slopes of Alberta. Leeson (CPS, pers. commun.) noted that sheep were apparently attracted to construction activity along the railway in Jasper National Park and to snow-making activity at a ski area in BNP. Elk and deer were not tolerant of construction activity and moved away while people and machinery were working.

4.2 ROAD-KILLS ON THE TWINNED HIGHWAY WITHOUT FENCING

4.2.1 RESULTS

There was no significant increase in mule or white-tailed deer road-kills within TCH II during the twinned but unfenced period. However, the number of road-killed elk and bighorn sheep in TCH II increased (Table 3).

To test the hypothesis that the increase in elk roadkills was due to presence of 1.5 m concrete medians along portions of the twinned highway, the kill distribution on the twinned highway in 1986 (medians present) was compared to the pre-construction road-kill distribution (no medians) and to a random distribution model (Table 4). These data showed that the 1986 road-kill distribution in TCH II was not significantly different from either the pre-construction model or the random model. Therefore, the hypothesis that presence of medians caused the kill increase could not be supported.

During 1986-87, when highway construction was completed in the TCH II bighorn sheep range, but the area was not fenced, the bighorn kills were nearly twice the pre-construction high for any 12 month pre-construction period (14 in 1983, 24 in 1986-87, Appendix 9). During the 1985-86 the biological year, a period of heavy construction work in the sheep range area, the road-kills were the lowest for any year since 1979.

During the period when TCH II was twinned but not fenced, there was not a concentration of road-kills at the TCH I end-of-fence. Nine percent (8 of 88) of elk road-kills happened within the first 1 km of the west fence end and 49% happened within the first 5 km. The 1 km sections with the most frequent elk road-kills were 1-2 and 4-5 km from the end-of-fence.

During the biological years 1985-89, when TCH I was fenced but the TCH east of the park was twinned but not fenced, 21% (12 of 57) of the elk road-kills happened within the first 1 km of the east fence end and 61% happened within the first 5 km. The 1 km sections with the most frequent elk road-kills were 0-1 and 4-5 km from the end-of-fence.

4.2.2 DISCUSSION

During the original environmental assessment of the project (Klenavic 1979, Paradine 1982), the potential impact of twinning on road-kill rates was predicted to be significant. In the absence of any other factor, would doubling the highway width increase, decrease, or not alter the road-kill rates? Singer (1975) had predicted no increase in elk mortality after expansion of a highway in Glacier National Park, Mont. He noted that most elk crossings were at night (when traffic would be reduced) and that the expansion to 4 lanes might create a barrier to elk movement. Falk et al. (1978) suggested that increased traffic volume on a highway frequented by white-tailed deer might deter deer from crossing and reduce the need for fencing.

Allen and McCullough (1976) compared road-kill rates on a 2 lane highway with kill-rates on a 4 lane highway and observed 300% more kills on the 2 lane highway. However, their results were not weighted for differences in traffic volumes or highway lengths. Reilley and Green (1974) showed a 500% increase in road-kills during the first 4 years a twinned highway was opened relative to a paralleling 2 lane highway. After several years the road-kill rate stabilized at 200% of the pre-existing 2 lane highway rate.

In Banff, the fact that TCH II was twinned for nearly 2 years before it was fenced provided an opportunity to examine the impact of twinning on kill rates for several species. Four candidate explanations have been proposed for the increase in elk and sheep kills: deflection from fenced areas, the presence of concrete medians, the longer transit time on a wider highway, and increased traffic speed on a twinned highway.

The data do not support the hypothesis that the fence simply deflected the elk road-kill problem to either end of fence. For the unfenced period of TCH II, the highest numbers of road-kills were not at the end of the TCH I fence. For the TCH east of TCH I, although the number of road-kills were high within 1 km of the end of fence, the road-kill numbers were matched by an unfenced highway segment 4-5 km east of the end-of-fence. Analysis of data from east of the park are complicated by 2 factors: potentially less consistent reporting and the physical presence of the Town of Canmore.

For bighorn, the restricted extent of the habitat overlapping the highway eliminated deflections from fenced zones as a candidate explanation. However, since the concrete median was installed throughout the bighorn sheep kill zone, it remains a potential explanation of increased sheep road-kills.

Neither species of deer had a significantly changed kill rate on TCH II after twinning and before fencing. This may be the result of small sample size. If this lack of change is true, it may suggest that species which frequently travel alone or in small groups, such as mule deer and white-tailed deer, are less vulnerable to increases in highway width than species such as bighorn sheep and elk which frequently travel in much larger group sizes. The larger group sizes would be exposed for a longer period as they crossed the highway and there would be an increased likelihood of passing cars intersecting a herd. Casual observations of elk herds divided by passing cars revealed that the animals on the "wrong" side of the highway became highly agitated and bolted across the road to join the main group. During 1 railway survey, I observed a herd of elk split by a passing train. One female separated from the main group and possibly from her calf, made repeated attempts to jump between the passing rail cars.

While the cause of the increased numbers of elk and sheep road-kills on the twinned, unfenced segment of TCH II during 1985-87 remains obscure, this work supports the validity of the concern expressed during the environmental hearings on the project.

Table 1. Number of man-caused ungulate mortalities*, BVER, 1985-89 by biological year.

Species / Year	Location						
	TCH East	TCH I	TCH II	TCH III	CPR	Other	Total
Elk							
85-86	5	8	47	30	30	8	128
86-87	4	2	45	37	49	8	145
87-88	2	3	2	38	33	8	86
88-89	7	2	0	23	26	10	68
Mule deer							
85-86	1	0	8	2	1	5	17
86-87	2	0	9	7	2	10	30
87-88	3	0	4	10	3	12	32
88-89	0	1	0	12	2	9	24
White-tailed deer							
85-86	0	1	6	6	0	2	15
86-87	0	0	4	4	2	0	10
87-88	1	0	1	9	2	0	13
88-89	6	0	0	12	1	4	23
Bighorn sheep							
85-86	0	0	5**	0	0	1	6
86-87	0	0	24	0	0	2	26
87-88	0	0	3	0	0	3	6
88-89	0	0	0	0	0	3	3
Moose							
85-86	0	0	3	1	1	2	7
86-87	0	0	1	1	0	1	3
87-88	0	0	0	1	0	1	2
88-89	0	0	0	1	0	0	1
All species							
85-89	31	17	162	194	152	89	645

* CPR train-kills, TCH road-kills, other sources

** Speed reduction in bighorn sheep zone in effect until October 1985

Table 2. Fencing effectiveness along TCH I (1985-89) and TCH II (1987-89).

Species Year	TCH I Post-fencing reduction(%)	TCH II Post-fencing reduction(%)
Bighorn sheep	n.a.	100*
Elk	93	98
Mule deer	97	88**
Moose	n.a.	100
White-tailed deer	97	97
All species	94	97

* excludes 3 bighorn sheep killed 1987-89 during fence installation
** excludes 2 mule deer killed during fence installation

Table 3. Chi² analysis of the change in road-kill distribution along TCH I and II before (1977-82) and after (1985-89) twinning relative to the untwinned TCH III*.

Species	TCH I : TCH III		TCH II : TCH III	
Year	Chi²	Significance**	Chi²	Significance
Elk				
85-86	25.48	S-	11.46	S+
86-87	51.18	S-	5.58	S+
85-87			38.98	S+
87-88	49.66	S-	22.47	S-
88-89	29.52	S-	16.66	S-
87-89			16.42	S-
Mule deer				
85-86	not calculated***		2.16	n.s.
86-87	8.2	S-	0.00	n.s.
85-87	10.57	S-	0.75	n.s.
87-88	11.74	S-	4.62	S-
88-89	11.22	S-	15.92	S-
87-89	22.83	S-	17.73	S-
White-tailed deer				
85-86	5.49	S-	0.18	n.s.
86-87	5.52	S-	0.12	n.s.
85-87	34.45	S-	0.60	n.s.
87-88	12.43	S-	8.59	S-
88-89	10.07	S-	15.27	S-
87-89	30.38	S-	23.64	S-

* TCH I was fenced throughout 85-89, TCH II was fenced starting in 87-88, TCH III was neither twinned nor fenced, see section 3.10, historic road-kill ratios

** n.s. not significant, S significant $P < 0.05$, S- significant reduction from historic ratio, S+ significant increase from historic ratio

*** fewer than 3 expected cases

Table 4. After twinning, pre-fencing* distribution of elk road-kills on segments of TCH II with grass medians (TCH-G) and with concrete medians (TCH-C) compared to the number of road-kills predicted by historic and random models**

Observed 1986	
Kills on TCH-C	44
Kills on TCH-G	16
Historic Model	
Expected kills TCH-C	45
Observed kills TCH-G	15
Chi^2	0.0089
P	0.7656 n.s.
Random Model	
Expected kills TCH-C	41
Observed kills TCH-G	19
Chi^2	0.9005
P	0.3427 n.s.

* only data from 1986 used because reduced speed zones and construction still effect during 1985

** historic model based on pre-fencing and pre-twinning road-kill distribution on TCH segments in which either grass or concrete medians were installed during twinning; TCH-C:TCH-G= 9:27 (0.25:0.75); random model based on relative length of TCH-C:TCH-G= 9.8:4.7 (0.676:0.324)
n.s. not significant, P >0.05

5.0 EFFECTIVENESS OF WILDLIFE UNDERPASSES

5.1 ELK

5.1.1 ELK MOVEMENT BEHAVIOR IN TCH I : RESULTS

Radio tracking elk commenced a year after TCH I was fenced. However, an adult female (code name Flora) collared in 1980 as part of park warden study (P. Jacobson, CPS, unpubl. data), was re-collared in TCH I in 1986. During 1981-82, this elk did not migrate and had an annual familiar area overlapping the TCH. During all 3 post-fencing years, she did not migrate and her familiar area continued to overlap the TCH with no extensions indicating movements around the end-of-fence (Figure 3). However, her frequency of crossing the TCH as indicated by her HCI dropped from a prefencing value of 24% (based on 74 locations) to post-fencing values of 2% (1986), 3% (1987), and 4% (1988).

O. TCH I after fencing. Photograph by John G. Woods

A total of 8 elk (6 females, 2 males), were collared in TCH I during 1986 and were located on 2,425 occasions from 1986-88 (Table 5). Pre- and post fencing data are not available for comparative analysis. However, most TCH I elk occupied ranges overlapping the fenced corridor. Point-by-point examination of locations did not indicate that elk were making regular movements around the ends-of-fence but rather were crossing via wildlife underpasses. During any year, 38-40% of the radio collared elk in TCH I made seasonal migrations. These animals made the longest distance migrations observed during the study (one-way route estimated >70 km) from the BVER to Mount Assiniboine Provincial Park in BC via the Spray River and Bryant Creek (Figure 4).

On 1987-08-02, I observed a group of 10 elk in the Powerhouse underpass. Seven of these elk including a collared female, calmly worked their way from south to north and back again. These elk spent several minutes of their transit time licking dirt beneath the highway drip lines.

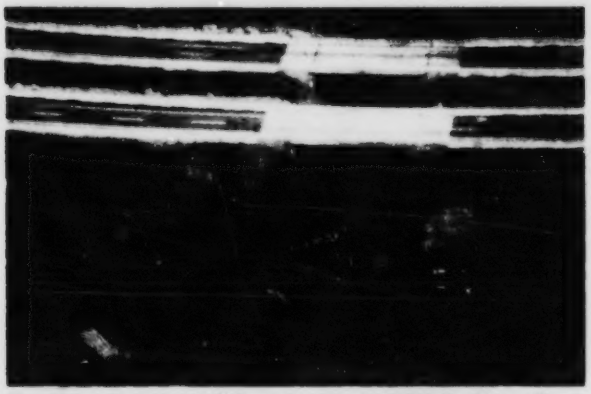
The warden service track count data for 3 wildlife underpasses in TCH I (East Gate, Duthil, and Morrison Coulee) were presented by Waters (1988). Using the Chi^2 test to examine the hypothesis that underpass use was uniform, the hypothesis was rejected in each case (Table 6). Elk used Duthil significantly more than East Gate and East Gate significantly more than Morrison Coulee.

5.1.2 ELK MOVEMENT BEHAVIOR IN TCH II: RESULTS

An adult female (current code name Shamrock, original code name Betty) collared in 1981 as part of the previous park warden study (Jacobson 1981 and P. Jacobson, CPS, unpubl. data) was re-collared in 1987 in TCH II. She occupied the same familiar area in 1987-88 as during 1982. This animal did not cross the TCH before or after fencing.

Forty-six elk (31 females,15 males) in TCH II were fitted with transmitters in 1986-87 and were located on 11,658 occasions from 1986-88

(Table 5). Pre- and post- fencing data are available for statistical analysis (Appendix 10).



P. Powerhouse wildlife underpass in TCH II. Note elk at entrance to underpass. Photograph by John G. Woods

Although all elk had a high degree of year-to-year fidelity to seasonal ranges and migration patterns, these movements were highly individualistic. During any year, 36-44% of the radio collared elk in TCH II made seasonal migrations. Two resident elk (code names Yearling2 and Dumpy) became migrants during alternate years. TCH II elk had the most complex migration patterns observed during the study (Figure 4). Migration routes included the Cascade River valley to Stoney Creek and Cuthead; 40 Mile Creek via Mount Norquay and Edith Pass; Elk Lake summit area via Mount Norquay; Marvel Lake and Wonder Pass via the Spray River; Sundance Creek cirques; Mount Bourgeau and Mount Brett cirques; and tributaries of Brewster Creek to Allenby Pass.

Of the elk which made traditional year-to-year migrations, many made summer migrations from the BVER to a high elevation range and back again each year. A few migrants made summer visits to the BVER while others made winter visits to their high elevation ranges. Most bulls made rutting migrations. A bull (code name Runway) made an autumn migration each year for 3 years after the rut (Figure 5). Another (code name Dougie) wintered at high elevation and summered in the BVER. The most complex pattern observed was by a bull (code name Lucky) which made up and down changes in elevation throughout the year.

A collared bull (code name Rocky) dispersed from TCH II during the study. It was collared in the Vermilion Lakes area in 1986 and migrated to the upper reaches of 40 Mile Creek that spring. Sometime during the summer, its transmitter failed. During the winter of 1986-87 it was seen in the BVER but then disappeared until March 1989 when it was seen and photographed along the Columbia River north of Golden, BC. approximatley 150 km west.

All mature collared bulls continuously tracked from September to September for 1 or more years returned to the same area each year during the rut. Most cow elk did not have definable calving areas although a female (code name Penny) calved within the Buffalo Paddock during all 3 years of the study.

Because of these highly individualistic movement behaviors, statistical analysis of year-to-year behavior change was restricted to individuals for which comparable data spanned at least 2 years. This created 3 categories for comparison: 1986 compared to 1987 (unfenced x fenced); 1986 compared to 1988 (unfenced x fenced); and 1987 compared to 1988 (fenced x fenced).

As can be seen in Table 7, familiar areas did not change significantly between years. The relative use of habitat north and south of the highway as indicated by the percentage of locations on the north side, did not change after fencing. The relative width of familiar areas parallel to the highway did not significantly change between years nor did point-by-point analysis indicate that elk travelled outside their normal familiar areas in order to get around the

western end-of-fence. There was no significant change in the numbers of familiar areas which overlapped the TCH before and after fencing. Nor did the data demonstrate significant changes in migration timing between years and the fence did not block the migration route of any radio collared elk for which pre-fencing data were available.

However, the data supported the view that relative frequency of highway corridor crossing decreased after fencing. However there was a significant increase again after the second year of fencing (Table 7).

During the winter of 1986-87, the recently erected highway fence and a pre-existing Buffalo Paddock fence created a narrow corridor at the north entrance to Grasslands underpass. Elk moving between the airfield and 40 Mile Creek frequently moved through this area. On several occasions, a large group of female and calf elk were observed in this constriction. These animals appeared to be very nervous and were not observed to use the underpass as a group. Similar observations were made by B. Leeson (CPS, pers. commun.) and J. Wackerle (CPS, pers. commun.). In 1988, the Buffalo Paddock fence was moved and the problem was apparently solved (R. Kunelius, CPS, pers. commun.).

The largest group of elk I observed crossing the fenced highway corridor was a group of 30 adult females and young on 1988-05-02 beneath the Five Mile Bridge. The group walked slowly from south to north. Smaller groups of elk were frequently observed using this bridge as an underpass.

In November 1986, fence construction separated 2 areas of montane range on the south side of the Minnewanka interchange adjacent to TCH II. On 1987-03-18, I observed 5 adult male elk including 2 collared animals walking across a CPR overhead bridge at this point. On 1987-06-18, I saw 1 adult female elk cross the overpass. On 1988-04-28, a mixed female-calf group of elk including 3 collared animals crossed the overhead. In all observations of overpass use, the animals involved appeared very calm.

5.1.3 ELK MOVEMENT BEHAVIOR IN TCH III: RESULTS

An adult female (code name Red) which had been collared in 1978 in the McCloud Meadows area of Kootenay National Park as part of a previous park warden study (Gibbons 1978) was re-collared in TCH III during 1987. She was killed by timber wolves before additional familiar area data could be obtained.

Nine elk (4 females, 5 males) in TCH III were fitted with transmitters in 1986-87 and were located on 1,807 occasions from 1986-88 (Table 5). Since TCH III was not fenced, these data are presented for comparison with the fenced TCH I and TCH II zones.

During any year, 67% of the radio collared elk in TCH III made seasonal migrations (Figure 4). Migration routes included Kootenay National Park via Vermilion Pass; a movement from the lower BVER to the upper BVER; and Yoho National Park via Kicking Horse Pass. Although not documented by radio collared elk, tracks indicated another seasonal movement between the BVER and the upper slidepaths along Redearth Creek. With 2 exceptions, migration movements in TCH III were simple spring-autumn movements to and from a higher elevation range. A bull elk (code name Skinny) performed a double migration similar to that illustrated in Figure 5. Another bull (code name Divide) had a complex movement pattern which featured year-round residency in the Lake Louise area, a rutting time downward movement to Field, Yoho National Park and a

winter downward movement to the Kicking Horse valley in Yoho.

Point-by-point analysis of individual elk movements did not indicate any change in elk movements relative to the TCH II end-of-fence.

5.1.4 ELK MOVEMENTS IN TCH I, II, AND III: DISCUSSION

Although no specific criteria to measure the success of underpass use were established before construction, the general management hypothesis suggests that a perfectly successful underpass network would allow free passage of ungulates without altering any natural process such as habitat utilization, migration, or predation rates.

Ward et al.(1980) reported that elk did not utilize an underpass in an ungulate-proof fence situation. However, the data presented in the present study indicates a high degree of success in use of crossing structures. Given that the complexity of seasonal movement behavior observed in the BVER exceeds that reported for any single elk population (Thomas and Toweill 1982, Woods and Hlady 1988), the apparent success within the first 2 years of fencing is remarkable and consistent with behavioral flexibility of elk as suggested by Morgantini (1988). The 1 exception to the lack of change in pre- and post fencing range use, the frequency of highway crossings, seems to be a logical consequence of the greatly reduced opportunities to cross.

Elk behavior within national parks may be quite different from hunted areas (Schultz and Bailey 1978, Rost and Bailey 1979). While the underpass system installed in this situation appeared to work very well for elk, it should be remembered that the majority of these elk live within the sanctuary of the park all year and have become habituated to humans. Underpasses installed in areas where elk flee from human presence (eg. in sport hunting areas) may not be as readily utilized.

Detailed comparison of open-span bridge design with a culvert design was not possible. Although both CPS and PWC were interested in the relative effectiveness of different underpass designs, each underpass in TCH I had individual site characteristics. Therefore, the relatively less frequent use of the culvert underpass in the system (Morrison Coulee) cannot be interpreted as a failure of this design. Elk made at least some use of every conceivable crossing structure including a restricted trail beside Carrot Creek and the CPR overpass which was specifically designed to be unattractive to ungulates.

In addition to individual underpass design, the relative frequency and position of underpasses probably had a large bearing on the project's success. Elk familiar area overlap with TCH I and II averaged 7 to 9 km (Table 5). The average distance between underpasses (including Cascade and 5 Mile Bridge) averaged 2.4 km. This spacing allowed each collared elk with a familiar area overlapping the TCH, to have at least 1 crossing opportunity within its traditional range.

5.2 MULE AND WHITE-TAILED DEER

5.2.1 DEER MOVEMENT BEHAVIOR: RESULTS

Although no mule or white-tailed deer have been radio collared in BNP, available evidence suggests that they have complex movement strategies similar to elk. As can be seen in Appendix 11, both species are killed in every month in the BVER on the TCH and the CPR. Therefore, at least some do not appear to make a seasonal altitudinal migration.

Of 17 mule deer killed in TCH IIIB (Castle to Lake Louise) during the biological years 1985-89, none were killed during the winter period (December through April). During the same period 7 were killed during the winter at lower elevations on the TCH in the BVER. Of 19 white-tailed deer killed in TCH IIIB during 1985-89, 1 was killed during the winter. During the same period 10 were killed during the winter at lower elevations on the TCH in the BVER. This suggests that both species of deer may make seasonal migrations between the lower and upper sections of the BVER in a manner similar to that described for some TCH III elk.

Incidental observations of both species of deer made while relocating radio collared elk, suggest that some deer migrate to high elevation ranges during the snow free period. However, in no case was a deer observed on high elevation elk ranges such as the north slopes of Cascade Mountain during the winter.

The warden service track count data for 3 wildlife underpasses in TCH I (East Gate, Duthil, and Morrison Coulee) were presented by Waters (1988). Using the Chi^2 test to examine the hypothesis that underpass use was uniform, the hypothesis was rejected in all cases (Table 6). Deer used East Gate significantly more than Morrison Coulee and Morrison Coulee more than Duthil. Deer use was significantly greater than elk use at East Gate and Morrison Coulee.

The only deer I observed using underpasses was a mule deer between the 2 sections of East Gate underpass. I observed 2 white-tailed deer (an adult male and adult female) and a coyote on 1987-07-08 crossing the CPR overhead at the Minnewanka interchange.

The ratio of deer tracks to elk tracks in TCH I underpasses was 1.2:1 (2411 deer tracks, 1942 elk tracks), Waters 1988).

5.2.2 DEER MOVEMENT BEHAVIOR: DISCUSSION

The lack of specific data on mule and white-tailed deer ecology in BVER is a major shortcoming in our understanding of the impact of the TCH on park ungulate populations. Track counts in underpasses do not distinguish deer species and these species have considerable behavioral differences (Wishart 1980). Although the data appear to support the management hypothesis, there may be specific differences which have not been detected.

Goodwin and Ward (1976) describe a successful fence/underpass system accepted by mule deer in Wyoming. Reed (1981) observed continued reluctant crossing behavior for mule deer using a 3.05 x3.05 x30.48 m concrete-box underpass over a 10 year period. They observed less reluctant use of a 4 x18 x14 m underpass and recommended open-span underpasses. Although several successful fence projects are reported in the literature for white-tailed deer road-kill problems, I did not locate any references to white-tailed deer underpass use. Initial results from a concurrent study of the Merritt-Peachland highway in BC indicate that both species of deer are using underpasses installed as part of that project (K. Simpson, Keystone Bioresearch, pers. commun.).

Although deer tracks outnumber elk tracks through TCH I underpasses, this is the reverse of their estimated relative abundance in the BVER (deer/elk ratio approximately 0.4:1, see sections 6.3 and 6.4). This may be a function of several factors including better acceptance of underpasses by deer. However, as has been observed in this and other studies (Bottini et al. 1986, Harper 1987), elk often spend several days in an area of their familiar area and then move to another area for a few days. Presumably they would only use underpasses when moving from area to area or when their tempo-

rary feeding area was adjacent to the fence. As has been observed in studies on the Merritt - Peachland highway in BC, deer may habitually bed in 1 area and feed in another for a prolonged period of time (K. Simpson, Keystone Bioresearch, pers. commun.). If a highway happens to separate deer bedding and feeding areas, a relatively few deer can account for a great number of tracks.

5.3 BIGHORN SHEEP

5.3.1 BIGHORN SHEEP MOVEMENTS: RESULTS

The radio tracking studies of bighorn sheep in the BVER indicate that this species has complex movements (Banff warden serv. unpubl. data). Individual sheep using the Vermilion Lakes area have annual familiar areas stretching north to the north end of the Palliser Range and west to the Mystic Pass area. (Banff warden serv. unpubl. data).

Bighorn sheep tracks were frequently observed in the Edith underpass before fencing and casual observations have been made of sheep using underpasses after fencing (Banff warden serv. unpubl. data; D. Huggard, University of BC, pers. commun.).

5.3.2 BIGHORN SHEEP MOVEMENTS: DISCUSSION

No reports of bighorn sheep use of underpasses were found in the literature.

5.4 MOOSE

5.4.1 MOOSE MOVEMENTS: RESULTS

Although moose have not been radio collared in BNP, available evidence suggests that they have complex movement strategies similar to elk (Sandegren and Bergstrom 1983). As can be seen in Appendix 11, moose have been killed throughout the year in the BVER on the TCH.

Q. TCH II in bighorn sheep use area. Note the escape terrain excluded by the fencing. Photograph by John G. Woods

At the present time the moose population in the BVER appears to be very small. During the 4 years of this project I had fewer than 20 observations. It is possible that these were dispersing animals rather than migrants or residents.

In 1985, I observed recent moose tracks through the Edith underpass in the TCH II before the highway was fenced in this area.

5.4.2 MOOSE MOVEMENTS: DISCUSSION

In Sweden, extensive fence/underpass systems have been used in road-kill situations (H. Flygare, Canmore, AB, pers. commun.). In North America, fencing/underpass systems have been installed in moose range on part of the Merritt-Kamloops highway and along the entire Merritt-Peachland highway. Initial results indicate that moose are using underpasses installed as part of these projects. (K. Simpson, Keystone Bioresearch, pers. commun.).

In light of the current low numbers of moose in the BVER, it is unlikely that underpass use by moose will be more than occasional.

Table 5. Elk movement characteristics determined by radio tracking, BVER, 1986-88.

Characteristic*	1986	1987	1988
TCH I			
Fenced (Y/N)	Y	Y	Y
Collared elk	8	6	5
Number FA-BVER Overlapping TCH	5	4	5
Total locations	731	819	875
Aver. FA (km2)	157	124	158
Aver. FA-BVER (km2)	22	23	17
Aver. FA-TCH overlap (km)	9	8	8
Aver. HCI	2	3	4
Percent use north of TCH	31	39	26
Number migrating	3	2	2
Aver. summer departure date	162	147	180
Aver. summer return date	292	300	284
TCH II			
Fenced (Y/N)	N	Y**	Y
Collared elk	25	38	32
Number FA-BVER Overlapping TCH	20	21	20
Total locations	2126	4385	5147
Aver. FA (km2)	73	61	64
Aver. FA-BVER (km2)	29	24	28
Aver. FA-TCH overlap (km)	9	8	8
Aver. HCI	9	3	4
Percent use north of TCH	41	42	36
Number migrating	9	13	13
Aver. summer departure date***	157	156	164
Aver. summer return date***	261	267	257
TCH III			
Fenced (Y/N)	N	N	N
Collared elk	6	6	6
Number FA-BVER Overlapping TCH	6	6	6
Total locations	371	377	1059
Aver. FA (km2)	118	122	139
Aver. FA-BVER (km2)	59	71	103
Aver. FA-TCH overlap (km)	25	28	30
Aver. HCI	17	16	9
Percent use north of TCH	69	70	72
Number migrating	4	4	4
Aver. summer departure date****	126	135	145
Aver. summer return date****	263	268	283

* terms defined in section 3.10

** fence not completed until September

*** excludes 2 adult males with complex seasonal movements

**** excludes an adult male with complex seasonal movements

Table 6. Chi² analysis* of relative use of TCH I underpasses (EG= East Gate, MC= Morrison Coulee, DU= Duthil), January 1985 to December 1987 based on track count data presented by Waters (1988).

Hypothesis	Observed	Expected	Chi²	Ho
Equal use of underpass pairs by elk				
EG x MC	662:147	405:405	327	rej.
EG x DU	662:1133	898:898	123	rej.
MC x DU	147:1133	640:640	760	rej.
Equal use of underpass pairs by deer**				
EG x MC	1069:736	903:903	61	rej.
EG x DU	1069:606	838:838	128	rej.
MC x DU	736:606	671:671	13	rej.
Equal use of the same underpass by elk and deer				
EG - Elk x Deer	662:1069	866:866	94	rej.
MC - Elk x Deer	147:736	442:442	393	rej.
DU - Elk x Deer	1133:606	870:870	160	rej.

* Chi² tests the hypotheses (Ho) that underpass use was equal between underpasses and between species, hypothesis rejected (rej.) if $P<0.05$

** white-tailed and mule deer tracks combined

Table 7. Results of statistical tests* for change in elk range use characteristics based on paired data from individual radio collared elk present for at least 2 of 3 years (1986-88) in TCH II when unfenced (UF86) and after fencing (F87,F88).

Characteristic	Comparison Pair		
	UF86xF87	UF86xF88	F87xF88
Total familiar area	n.s.	n.s.	n.s.
BVER familiar area	n.s.	n.s.	n.s.
Familiar area overlap with TCH II	n.s.	n.s.	n.s.
Number of BVER familiar areas overlapping TCH II	n.s.	n.s.	n.s.
Highway crossing index (HCI)	S-	S-	n.s.
Percent use on 1 side of TCH II	n.s.	n.s.	n.s.
Summer migration departure date	n.s.	n.s.	n.s.
Summer migration return date	n.s.	n.s.	n.s.

* see Appendix 10 for details
n.s. no significant change
S - significant reduction from first to second year of pair, $P < 0.05$

Figure 3: Adult cow elk code name" Flora" familiar area before and after fencing TCH I.

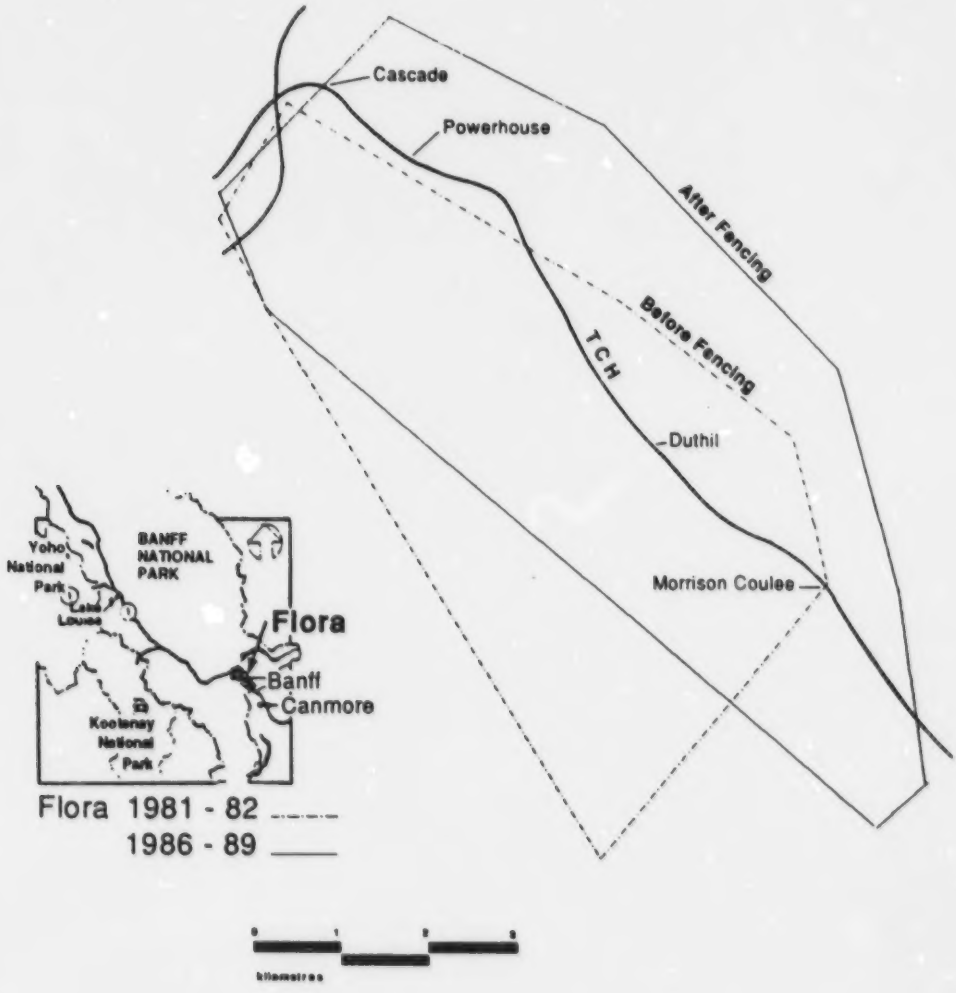


Figure 4: Migration routes for BVER elk

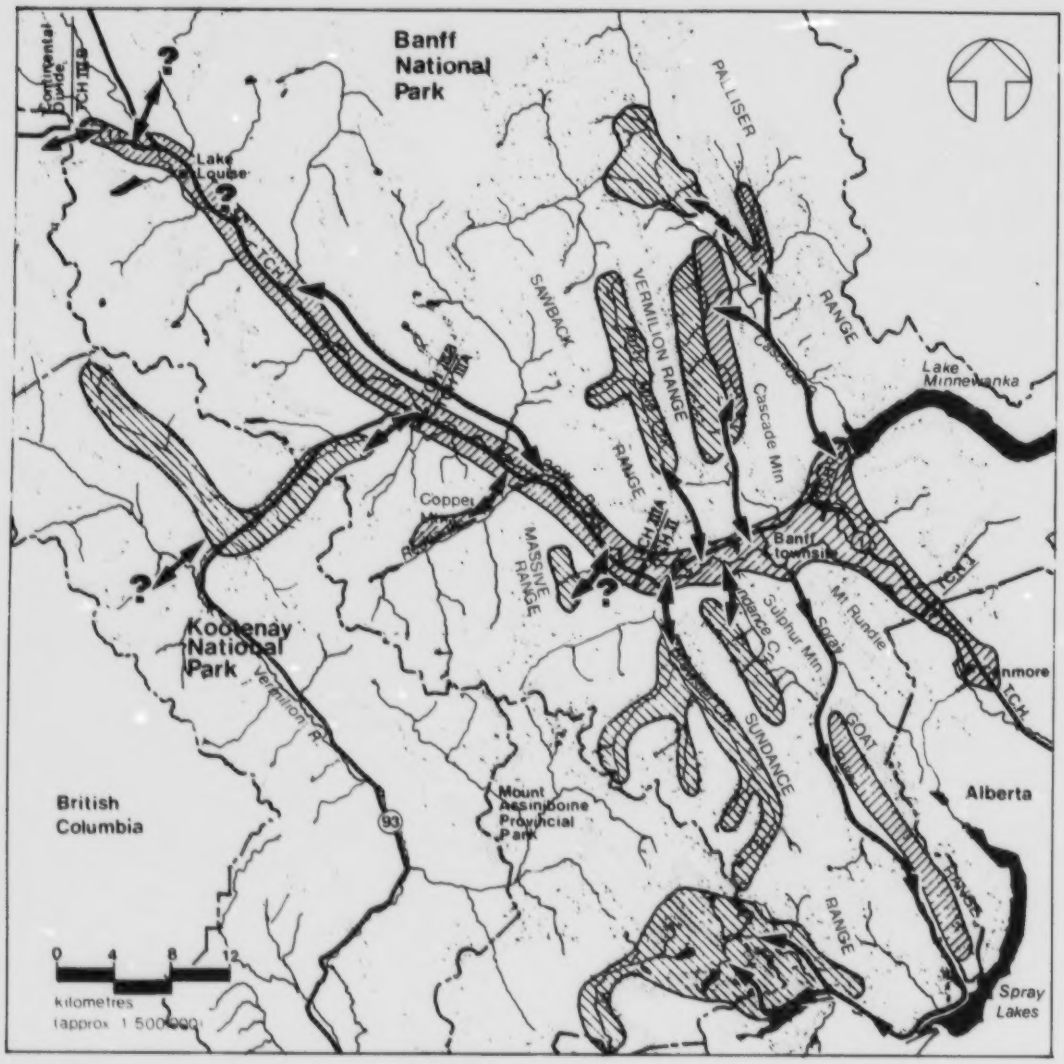
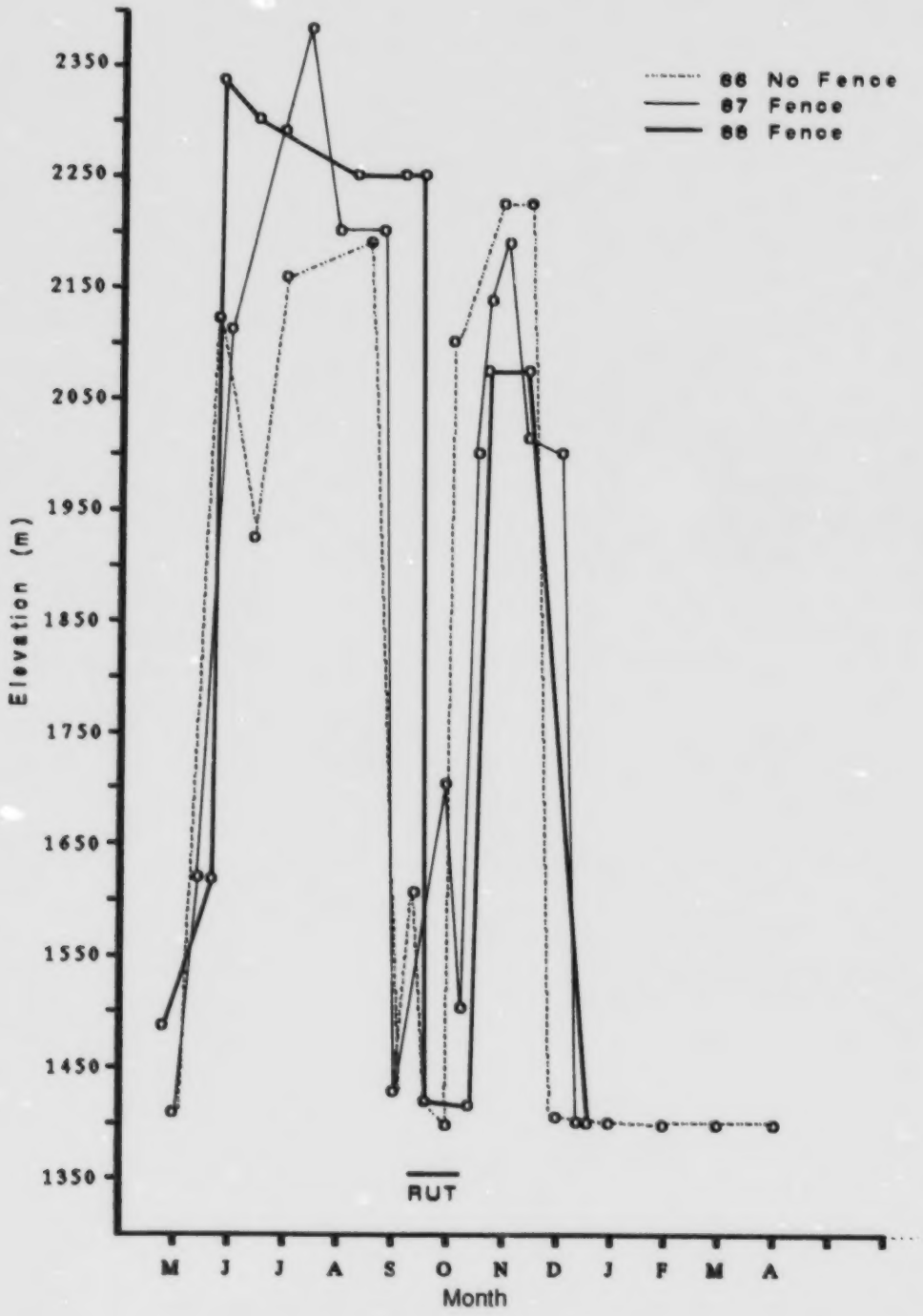


Figure 5: Adult bull elk code name "Runway" elevational movements, 1986-88, BVER, TCH II. Movements between high and low ranges required crossing TCH II



6.0 UNGULATE POPULATION BENCHMARKS

6.1 ELK

6.1.1 HISTORICAL REVIEW TO 1985

Holroyd and Van Tighem (1983) reported on archaeological evidence for native elk in the BVER. Historical evidence includes observations by the Palliser expedition in 1858 (Banfield 1952) and mention of elk in Rocky Mountains National Park Superintendent Reports (Douglas 1903).

By 1906-07, elk had disappeared from the BVER and from much of their historic range in the Canadian Rockies (Holroyd and Van Tighem 1983). Localized populations were known in the Siffleur River, in the Kananaskis River valley south of the BVER, and in some adjacent watersheds in BC. Superintendent reports frequently mentioned over-harvest by humans as the probable cause of their extirpation (Douglas 1903).

In 1915, the first native elk in a decade were reported by the park superintendent (Clarke 1916) within the BVER. These were animals making summer migrations into the park from BC (probably via Vermilion Pass at Castle Junction). They did not winter in the BVER.

In 1918 and again in 1920, a total of 235 elk originally from Yellowstone National Park, Wyoming were shipped to the park and released in the BVER where they rapidly increased in number (Lloyd 1927).

The first elk reported in collisions in the BVER were railway kills: 18 in 1929, 12 in 1930, 10 in 1931, and 121 in 1932 (Holroyd and Van Tighem 1983). During the deep snow winter of 1946-47, Mitchell (1947) estimated that 50 elk were killed on the railway. Green(1957) reported that about 4 elk per year during 1944-54 were killed on park roads.

Beginning in 1941 and ending in 1969, the park conducted slaughters most years to suppress elk numbers in the BVER (Holroyd and Van Tighem 1983). During this interval, 3923 elk were culled, with a peak annual kill of 352 in 1946.

These reduction programs were based on the perceived inability of elk to achieve a stable K_1, to avert potential die-offs of elk during harsh winters, and to reduce competition between elk and other ungulates in the BVER. Mitchell (1944) noted that "..we can only try and hold down the numbers of elk to a reasonable number so that in the event of a hard winter the mortality of elk and deer will not be too high." Flook (1970) expressed the concern in the following way: "In several of the national parks wapiti (elk) increased to such high levels that they damaged the stands of forage plants on the ranges where they gathered in winter. This resulted in food shortages and was probably the cause of declines in the numbers of mule deer and moose."

Houston (1982) reports on a similar rationale which resulted in elk reduction programs lasting from 1923-69 in Yellowstone National Park. Unlike Yellowstone, timber wolves were part of the BVER ecosystem during part of the control period.

At the start of this period, Mitchell (1944) estimated about 1200 elk in the BVER based on observed numbers of 600. Between 1944-53, minimum reported elk populations in the BVER ranged from 190 to 593 (Green 1957). A late autumn ground census in 1963 by park wardens counted 614 elk with an estimated total

population of 814 (Flook 1967). From 1962-66, elk populations were reported to range from 250 to 610 in late September and October (Flook 1967). In 1974, shortly after the slaughter program ended, Bobek et al. (1982) reported the population at 30 animals. This was undoubtedly an error since 45 elk were killed on the TCH and CPR the next year (Appendix 9) and Holroyd (1979) estimated 372 elk in 1976. However, it appears that elk populations were very low in the early 1970's.

During the extreme winter of 1971-72, snow depths were 2 to 3 times deeper than recent averages and a large elk kill was recorded on the CPR (Kutzer 1972, Kutzer 1974). During the following decade, the number of highway kills steadily increased while the CPR kills fluctuated widely from year-to-year (Appendix 9). By 1985, the park warden service had instituted a formal elk census procedure (Kunelius 1985) and the early spring count corresponding to the entire BVER was 795 (data to follow).

6.1.2 RECENT POPULATION ESTIMATES

6.1.2.1 DIRECT COUNTS

The results of early spring elk counts from 1985 to 1989 by the park warden service are presented in Table 8. The average for the years 1986-89 was 912 with a range of 795 to 955. Although these data illustrate fluctuations up and down, confidence intervals for each count may well exceed this fluctuation.

Caution should be used in comparing these data to years before 1985 because the census area was not standardized before that date. It also should be remembered that these are all minimum counts of actual animals seen, the true N in every case must be larger than this observed figure.

6.1.2.2 GROUND MARK-RECAPTURE ESTIMATES

The results of early spring ground mark-recapture estimates of the elk population for the years from 1986 to 1989 based on elk collared in this study are presented in Table 8. The average for the 4 years is 912 with a range of 74. Although these data illustrate fluctuation up and down for the years in question, confidence intervals for each count may well exceed this fluctuation.

6.1.2.3 RECONSTRUCTION BASED ON HIGHWAY DEATHS

During the interval 1986-01-20 to 1989-04-31, the estimated adult elk annual mortality rate due to the TCH was 0.0374 (data to follow). During the same interval, an average of 37.19 adult elk per year were recorded as road-kills along the TCH in the BVER. Therefore, the average reconstructed early spring population based on these data was 994. During the full biological years 1986-89, when the estimated annual mortality rate due to the TCH was 0.0318, 35 adult elk per year were found along the TCH and the reconstructed early spring population estimate was 1101.

6.1.3 RECRUITMENT ESTIMATES

6.1.3.1 CONCEPTION AND BIRTH DATES

Flook (1970) estimated the mean conception dates for BVER elk to be September 11 with peak rutting activity to be in the period September 8-21. Green (1957) and Struhsaker (1967) and incidental observations made during this study, confirm peak rutting activity from mid to late September with some rutting activity commencing in late August and extending until mid October.

Assuming a 256 day gestation, the predicted peak in elk births would be May 24th. During this study the first elk calf was seen on May 15th and the birth period extended until late June.

6.1.3.2 PREGNANCY RATES

Of 29 pregnant road-killed elk examined in this study, all carried a single fetus. During the period 1944-54 in the BVER, 1 case of twin calves was reported in a sample of 571 pregnant cow elk (Green 1957).

No pregnant 01 age class elk were found within the BVER sample (N=4). Elk older than 01 had a pregnancy rate of 0.73 (N=41). The pregnancy rate for all elk age 01 and older was 0.67 (N=45). Flook (1967) reported a yearling pregnancy rate of 0.21 (N=82, annual range 0.00 to 0.50) and a pregnancy rate of 0.91 (N=654, annual range 0.81 to 0.97) for age class 02 and older during the years 1958-1967. In Flook's sample, the pregnancy rate for all elk 01 and older was 0.83 (N=736).

6.1.3.3 CLASSIFIED COUNTS

Results of autumn and spring classified counts 1985-89 are presented in Table 9.

Autumn calf:cow ratios were significantly higher in October 1985 (57.4) than during 1986-89 (average 43.1). The average autumn calf:cow ratio for all years 1985-1989 was 46.0. Although Flook (1967) did not provide confidence intervals for his BVER classified count data, his autumn October 1963 ratio of 54.6 was within the range of values observed during this study.

Several other authors have presented calf:cow ratio data for the BVER. Holroyd (1979) reported an autumn calf:cow ratio of 63:100 for the autumn of 1976 based on a sample of 327 classified elk. Holroyd and Van Tighem (1983) calculated autumn calf:cow ratios based on warden diary reports as 18:100 for the years 1975-80. Green (1957) presented extensive data for 10 autumns in the period 1944-53 which ranged from 13-45:100. In the absence of standardized methods and reported confidence intervals, it is difficult to comment on these previous data except to note that that the differences may reflect differences in methods rather than real differences in the population composition.

Spring calf:cow ratios were very similar during all 4 years of the study with a marginally significant difference between April 1987 (29.8) and April 1988 (21.8). The average spring calf:cow ratio for all years 1986-89 was 25.0. Flook (1967) did not report spring calf:cow ratios for the BVER.

The pooled spring calf:cow counts 1986-89 (331:1326) were significantly lower than the average autumn calf:cow ratio (Chi^2=102.0, P<0.001).

Autumn age class 01 bull:cow ratios averaged 11.4 with a range of 7.4 to 13.6. Flook (1967) reported a spike bull:cow ratio of 12.4. Spring age class 01 bull ratios averaged 8.5 with a range of 7.0 to 11.9. The pooled spring age 01 bull:cow counts 1986-89 (112:1326) were significantly less than the average autumn ratio (Chi^2=9.3 and P<0.002).

Autumn age class >01 bull:cow ratios averaged 22.5 with a range of 14.8 to 35.1. Flook (1967) reported an autumn age >01 bull:cow ratio of 28.5. Spring age>01 bull: cow ratios averaged 13.6 with a range of 7.9 to 17.4. The pooled spring age >01 bull:cow counts 1986-89 (177:1326) were significantly less than the average autumn ratio (Chi^2=43.5 and P<0.001).

6.1.4 AGE DISTRIBUTION OF TCH AND CPR KILLS

The age distribution of TCH and CPR kills is presented in Appendix 12. The calf:cow ratio of the TCH kills was significantly higher than the pregnancy rate (Chi^2=9.3, P=0.002). The calf:cow ratio of CPR kills was similar to late winter classified counts for the population. For

both TCH and CPR class 01 male kills and >01 male kills, the observed male:cow ratios were larger than any classified count ratios. This could be because males are more likely to be hit on the TCH and CPR, or that males are under-estimated in classified counts.

R. Adult male elk crossing the CPR. Photograph by Doug Leighton

6.1.5 MORTALITY ESTIMATES

6.1.5.1 MORTALITY RATES

Elk mortality rates (M, the proportion of the population dying during any year) were estimated from deaths of radio collared elk (Table 10). During the period January 1986-89, collisions on the TCH were the leading cause of death of radio collared elk. The average M before fencing TCH II was 0.103. After TCH II was fenced, the average M was 0.011. Timber wolves were the second rank cause of radio collared elk death with a pooled 1986-89 M of 0.067. Before fencing TCH II, the total man-related mortality rate was 0.115. After TCH II fencing, the total man-related mortality rate was 0.015. While these data are consistent with the numerical reduction in elk road-kills after fencing, in the absence of confidence intervals, their statistical significance cannot be assessed.

S. Adult female elk killed by timber wolves. Note large bite out of the rear leg. Photograph by John G. Woods

6.1.5.2 PARASITES

The prevalence of giant liver flukes, lungworms, and hydatid cyst tapeworms in elk is presented in Table 11.

The 1985-89 prevalence of giant liver flukes in elk older than calves was 78%. During the first years of the elk slaughters (1941-58), giant liver flukes were not observed in the BVER population (Green 1957). The first flukes were found in December 1959 (Flook 1967). By the biological year 1964-65, the prevalence was 50% for elk older than age class 00 (Flook 1967).

Two collared elk in this study (code names Longshot and Yearling2) apparently died of massive giant liver fluke infestations. These are the first reported elk mortalities implicating this parasite (M. Pybus, Alberta Wildlife, pers.

commun.). Several other radio collared elk died in similar circumstances but their livers were consumed by scavengers. The actual mortality rate due to liver flukes may be higher than the reported rate (Table 10) because of the problem of determining cause of death from partially scavenged carcasses.

Hydatid cyst prevalence during 1985-89 was 31% in elk older than age 02. Green (1957), Flook (1967), and Flook and Stenton (1969) reported hydatid cysts and lungworm in BVER elk. Flook (1967) reported 24% of elk older than 02 had hydatid cysts in the 1960's.

Lungworms were found in 44% of the age class 01 examined during 1985-89. Data presented by Flook (1967) for lungworm in BNP and Kootenay during the years 1958-66 indicated a prevalence of 1% in age class 00, 6% in age class 01, 5% in age class 02, and 2% in age class 03 and older.

T. Field necropsy of adult bull elk code name Longshot which died of massive giant liver fluke infestation. Photograph by John G. Woods

6.1.5.3 PREDATION

Green (1957) listed grizzly bear, black bear, cougar, coyote, and timber wolves as elk predators in the BVER. Of these, timber wolves are the only carnivores known to prey extensively on elk.

Timber wolf numbers have fluctuated widely in the BVER since the 1930's (Green 1951, Green 1957, Holroyd and Van Tighem 1983). In 1985, timber wolves had apparently recently re-occupied the BVER after a period of absence (R. Kunelius, CPS, pers. commun.). During 1985-89, wolf kills were frequently encountered and 4 of the radio collared sample of elk were killed by wolves (Table 10).

The sex-age composition of elk killed by timber wolves is highly non-random. In a sample of 53 kills from 1985-89, 11 were adult cows, 17 calves, and 25 bulls. The calf:cow ratio in wolf kills is significantly greater than the elk pregnancy rate (Chi^2=5.4 and P=0.02). The bull:cow ratio in wolf kills is significantly greater than any observed ratio in the population or the theoretical bull:cow ratio at conception (Chi^2=5.44 and P=0.02).

Although there were 2 cases in which the fence apparently facilitated elk capture by coyotes or wolves, there was no indication that this happened on a regular or significant basis (see Bighorn Sheep).

Although coyotes commonly scavenged elk carcasses, no cases of coyote predation on elk were documented. One case of black bear predation on an calf elk and a cougar predation on an adult elk were documented by the park warden service during the study (M. Gibeau and R. Kunelius, CPS, pers. commun.).

6.1.5.4 CPR COMPARED TO THE TCH

Ungulates other than elk were rarely killed on the CPR (Table 1 and Appendix 9). About one-half of the TCH road-kills were other species. Two radio collared elk were killed on the CPR during the study while 5 were killed on the TCH (Table 10). In terms of timing, 66% of the CPR elk kills happened during the months of Decem-

ber through March compared to only 24% of the TCH elk kill during these months (Figure 6, Appendix 11).

During years of heavy snowfall, elk may be particularly prone to train-kills but the road-kill rate may be unaffected (Appendices 1-4, 9). Mitchell (1947), Van Tighem (1980) and Kutzer (1972, 1974) all implicate deep snow winters in increased elk train-kills.

6.1.5.5 ELK HARVEST OUTSIDE THE PARK

Some radio collared elk made regular movements outside the park where they were subject to sport hunting. Both collared elk (code names Doubleo7 and Jogger) killed by hunters (Table 10) in this study were shot in the Canmore area by bow hunters. An adult female elk collared by P. Jacobson in the previous radio tracking study was killed by a rifle hunter at Spray Lakes.

6.1.6 MOVEMENTS

6.1.6.1 IMMIGRATION AND EMIGRATION

Only 1 case of emigration by collared elk was observed, from the BVER to Golden, B.C. (see 5.1.2). Two cases of apparent immigration into the BVER were noted, both from Kootenay National Park (see section 5.1.3). One was an adult female radio collared at McCloud Meadows. The other an adult female ear-tagged just west of the Continental Divide in Vermilion Pass. Morgantini (1988) reported a collared elk immigrating to the BVER from Kootenay and then emigrating via the Pipestone River to the Ya-Ha Tinda Ranch in the Red Deer valley.

6.1.6.2 SEASONAL MIGRATIONS

Details on seasonal migrations were presented in sections 5.1.1 through 5.1.3. During any year of the study, between 51 and 58% of the radio collared elk did not migrate (Table 5). Travel patterns of the remaining elk were complex and included most valleys radiating from the BVER (Figure 4). These data illustrated that the BVER is not a closed system from a management point of view. Some elk which wintered in the BVER within thepark spent part of the year outside BNP in the Canmore area, the Spray Lakes, Mount Assiniboine Provincial Park, Kootenay National Park and Yoho National Park. These trans-boundary elk are subject to sport hunting in the Canmore and Spray Lakes areas.

These migrations illustrate that elk road-kills on the TCH and CPR have effects which influence an area considerably larger than the BVER. Similarly, the positive actions of reducing these kills through fencing and underpasses will be extended to other areas which share BVER elk on a seasonal basis.

Morgantini (1988) presented data on the Red Deer River elk population to the north of the BVER. In contrast to BVER elk, almost all Red Deer elk wintered on the Ya-Ha Tinda Ranch and migrated into the park. In their farthest extension, some elk from the Ya-Ha Tinda spent the summer just north of the BVER in the Lake Louise area. These elk also contrasted with the BVER elk in their migration timing. BVER elk made rapid migratory movements from the wintering area directly to their summering area. The only exceptions to this were adult females which gave birth en route. Morgantini (1988) reported a 2 stage spring and autumn migration for that population. This migration was characterized by a rapid shift from the Ya-Ha Tinda to an "intermediate" range, and then a second step

to the summer range. Similarly in the autumn, elk staged at an intermediate range before returning to the ranch.

A possible explanation for the differences in migratory behaviors of the 2 populations would be the fact that most Red Deer River elk winter outside the park where they are subject to hunting. Only a small segment of the BVER population is subject to hunting and most are not habituated to humans. Disturbance during the May long weekend may push the Red Deer elk prematurely from the winter range and onto the intermediate range inside the park where they stage until ready to complete their migration. In the autumn, the presence of hunters at the ranch may cause elk to delay their return.

It is interesting to note that the latest returning migrants encountered in this study were the elk exposed to autumn rifle hunting on their return from the Bryant Creek- Mount Assiniboine area. Supporting this behavioral influence of human disturbance, park wardens noted several years after the autumn slaughters began in the BVER, elk appeared to be delaying their return to the winter range (Green 1949).

6.1.7 SEASONAL DIETS

6.1.7.1 FECAL FRAGMENT ANALYSIS

Seasonal diet information for the elk in the BVER is presented in Table 12. These data illustrate that elk are primarily leaf eaters all year. They eat the blades of grass and sedge for most of the winter but shift their diets to shrub leaves during the summer.

The high summer percentages of Elaeagnaceae are of particular note. Two species, *Elaeagnus commutata* and *Shepherdia canadensis*, are found in the BVER but cannot be separated by fragment analysis. However, *Elaeagnus* is restricted in distribution to the lower elevations of the BVER. *S. canadensis is* widespread throughout the BVER and also occurs in the upper subalpine ecoregion. Since Elaeagnaceae occurred in diets from all elevations, I assume that much of this material is *S. canadensis*. This conclusion is supported by numerous casual observations of elk eating *S. canadensis* leaves and by similar findings in Kootenay National Park (D. Poll, CPS, unpubl. data).

In a review of North American elk feeding habits, Kufeld (1973) ranked *S. canadensis* as valuable elk forage in the autumn, and as little value in winter and spring. He did not present a summer ranking for leaf use. Murie (1951) observed that elk eat the leaves in summer and the twigs in winter. Casual inspection of *S. canadensis* in the BVER indicated very little hedging although occasional plants had been heavily hedged by browsing woody material. Leaf striping rarely injured the current year woody growth.

Although feeding habits were not formally studied for other ungulates in the BVER, all winter season moose and deer stomachs examined contained twig particles rather than grass.

6.1.7.2 FECAL PROTEIN

Results from fecal protein analysis in the BVER are presented in Figure 7 and Table 13. These data illustrate a seasonal cycle with peaks in fecal protein during summer and minima during winter. The BVER fecal protein profiles closely follow the data presented by Morgantini (1988) for the Red Deer elk population (Table 13). Fecal protein is thought to parallel forage quality in generalist herbivores and is an indicator of range quality. See Morgantini (1988) for a general discussion.

6.1.7.3 FORAGE QUALITY

Results from sequential fiber analyses of mixed grasses, *Salix* spp., and *S. canadensis* forage samples are presented in Table 12. Some previous data on forage quality was presented for the BVER by Bobek et al. (1982) and comparative data is available for the Red Deer River herd (Morgantini 1988). These data illustrate the chemical phenology of the principal elk foods in the BVER. The benefit of switching from grasses to shrub leaves is evident in the summer protein values of *S. canadensis* and *Salix*. In winter, *S. canadensis* and *Salix* twigs have higher protein content than grasses but their very high lignin content may make them largely indigestible. In addition, *S. canadensis* twigs are known to contain phenolics which inhibit protein digestion (Sinclair et al. 1982). Presumably these phenolics are not present in the leaves.

Given the high seasonal importance of these 3 elk diet groups, their presence adjacent to railway and highway rights-of-way may increase the time elk spend near the rights-of-way and are exposed to collision hazards.

6.1.8 MORPHOLOGICAL CHARACTERISTICS

6.1.8.1 BODY WEIGHT

Whole body weight data for 129 elk salvaged during this study are presented in Appendix 13. Age class 03-10 males averaged 339 kg with the heaviest animal weighing 471. Age class 03-10 females averaged 238 kg with the heaviest animal weighing 311 kg. Confidence intervals (P=0.05) did not overlap between males and females in these age classes. In the age class interval 03-10, there was no significant difference from the data presented by Flook (1967) except for age 06 males..

6.1.8.2 ANTLERS

Dried antler weights and number of antler points data for elk killed on roads and the railway in the BVER, 1985-89 are presented in Appendices 14 and 15.

There were no significant age specific differences in antler weights for elk examined in this study compared to the data presented by Flook (1967) for the same population during 1960-63. McCorquodale et al. (1989) presented antler data for a colonizing elk population of Rocky Mountain elk *C.e.nelsoni* in Washington State which was presumably far below K_1. For all male elk examined (ages 02-08), all but 1 set of antlers was greater than the 95% confidence interval for BVER presented by Flook (1970). In a recent examination of elk antlers from Yellowstone National Park (D. Vales, pers. commun., unpubl. data), antlers were found to be similar or slightly greater in weight than the BVER antler data collected in this study. The Yellowstone population was thought to be at or slightly above K_1.

All road and train-kill age 01 male elk had 1 point although 2 yearlings killed by other causes had 2 point antlers. Age 02 elk males had 3 to 6 points (sample size 3), and 78% of age 03 males had 5 points. Seventy-nine percent of males > age 04 had 6 points. These data are in general agreement on BVER elk antler configuration notes presented by Green (1957) for the period 1944-48. In contrast, McCorquodale et al. (1989) reported that 75% of age 03 elk had 6 points and of the age >04 sample, 38 and 43% had 6 and 7 points respectively.

For the reasons reviewed by McCorquodale et al. (1989), antler characteristics may be valuable indicators of population condition and thus proximity to K_1. However, between-range comparisons (BVER, Washington, Yellowstone) should be made with caution.

Differences may reflect the genetic background of the population and the inherent characteristics of the range (forage quality, growing season, etc.) as well as the population's position relative to K_1. The comparative data for 2 periods of time (1960-63 and 1985-89) for BVER elk is unique in the North American elk literature. If natural or man-induced changes (eg. fencing, highway twinning) cause the population to change in size, it will be possible to test the value of antler morphology as an indicator of position relative to K_1. For the same reason, antler morphological data are currently being gathered for Yellowstone National Park elk.

6.1.8.3 JAW LENGTH

Jaw length data for 182 elk are presented in Appendix 16. No comparable BVER data from other periods exist. Although jaw length was found to be positively correlated to antler weight (r^2=73.7 for road and train-kill sample), the utility of jaw length as an indicator of K_1 is unknown. However, since jaws are relatively easy to collect and available for both sexes, this sample can be used for future BVER population condition comparisons.

6.1.8.4 KIDNEY FAT INDICES

Kidney fat indices are presented in Appendix 17. These indices are in general agreement with data from Flook (1967) which illustrated a seasonal cycle in fat condition and that adult males enter the winter with smaller fat reserves than adult females.

6.1.8.5 ELK CARRYING CAPACITY (K_1)

A central question to the management of elk populations in the BVER is their position relative to K_1- the ecological carrying capacity of the range (Houston 1982). Where is the current population with respect to K_1 and what signposts can be used in the future to assess K_1?

The most obvious way to assess K_1 for the BVER would be to remove all man-related elk mortality and let the system reach an equilibrium. This is essentially what was done in Yellowstone National Park and resulted in a 5 fold increase in elk numbers (Houston 1982). At the present time, determination of a natural K_1 is not possible because significant man-related elk mortality sources continue to exist on non-fenced roadways in the park and along the CPR.

The BVER situation also differs from the Yellowstone experiment in at least 2 other significant ways: the presence of timber wolves and an extremely high incidence of giant liver fluke parasites. Therefore, although the BVER elk population has benefited from the reduction in mortality through cessation of the slaughter program and fencing, population increases comparable to Yellowstone are unlikely.

The population parameters and morphological data gathered in this study provide a benchmark from which to assess future population condition and to compare condition with previous studies by Green (1957) and Flook (1967) of BVER elk and with parameters from other populations with known relationship to K_1.

Present evidence suggests that the BVER population is at or slightly above the 1963 population estimate of 807 presented by Flook (1967). In terms of whole body and antler weights, the current population is indistinguishable from the 1963 population and the sex-age composition is very similar. However, there are notable differences. First, the prevalence of giant liver flukes has increased dramatically and this parasite is now a documented mortality source for the species. Secondly, timber wolves were rare in the BVER in the 1960's and are now the leading documented cause of elk mortality in the BVER. Thirdly,

the pregnancy rate of age 01 and age class >01 are significantly lower than reported by Flook (1967). And lastly, collisions on both the CPR and TCH remain higher than reported by Flook.

In a study of an increasing population re-colonizing a recently depopulated range, Merrill et al. (1987) present data for a Roosevelt elk (*C.e.roosevelti*) population presumably very much below K_1. They reported a yearling pregnancy rate of .31 based on lactation and uteri inspection. Elk 01 and older had a pregnancy rate of .75. The pregnancy rate observed in BVER was not appreciably different (0.67).

Demarchi et al. (1983) presented another approach to determining the ecological carrying capacity of different quality elk ranges in BC. They suggested carrying capacities for high to very high capability rankings in the range of 6.6 to 19.5 elk per km^2 per year. Assuming 330 km^2 of elk range in the BVER, this suggests that K_1 may lie between 2178 and 6435. If these relationships hold for BVER elk, then the current population of approximately 900, is somewhere between .4 and .1 of K_1. The current population appears to be well below any intrinsic carrying capacity of the range and therefore can be expected to increase if mortality sources (such as road-kills) are decreased.

6.2 MOOSE

Moose were rarely seen during this study. As noted by Holroyd and Van Tighem (1983), moose were apparently more abundant in former years. In the late 1940's and early 1950's, Mair (1952) described them as "more easily observed (than elk) in summer". He counted 27 between Banff and 17 Mile Flats (west of town) in 1949 (Mair 1949).

No direct estimates of moose populations were made during this study. If the assumption is made that moose were equally susceptible as elk to collisions with automobiles on the TCH, then their relative abundance in the road-kill data from 1986 to 1989 (Table 1) may be a reflection of their relative abundance in the BVER. If this is the case, their abundance relative to elk would be 0.03 (population estimate 27).

Holroyd (1979) expressed concern over the future of moose in the BVER when he stated that moose are "particularly vulnerable to both highway and railway traffic in the Bow valley" and that "it is doubtful if natural increase is keeping up". However, during the past 2 decades, the ratio of mule deer to moose involved in highway kills has remained relatively constant (6.9:1in 1970-83 and 6.0:1 in 1984-88). This may be because both populations are changing in unison. Alternatively, there may not be a definable BVER moose population but rather a constant influx of dispersers.

The highest numbers reported in recent years was 30 at Vermilion Lakes in February, 1972 (Holroyd and Van Tighem 1983). However, this was at the peak of the heaviest snow winter on record, with 124 cm of snowpack in the Banff area. Therefore, it seems likely that the moose were concentrated because of extreme snow conditions. During this study, the maximum number of moose seen at a time was 4 (October 1985) and fewer than 20 were seen in total over the course of the study.

During the heavy snowfall winter of 1971-72, 12 moose were killed on the CPR. This is the record for any year in the BVER (Appendix 9). Child (1984) noted the potential impact of a railway on moose populations in northern BC.

Giant liver flukes are found in BVER moose (Table 11). Although flukes cannot mature in moose, they cause considerable damage to liver tissue and may predispose moose to a variety of other natural mortality sources (M. Pybus, Alberta Wildlife, pers. commun.).

6.3 MULE DEER

Mule deer were regularly seen during this study although no direct estimates populations were made. If the assumption is made that mule deer were as susceptible as elk to collisions with automobiles on the TCH, then their relative abundance in the road-kill data from 1986-89 (Table 1) may be a reflection of their relative abundance in the BVER. If this is the case, their abundance relative to elk would be 0.22 (population estimate 198).

Holroyd and Van Tighem (1983) reviewed mule deer studies in BNP and Jasper National Park and noted that "it is unlikely that present mule deer populations in Banff and Jasper can continue to sustain the existing level of highway and railroad mortality without declining". During 1976-78, they estimated that the population would have to exceed 175 to sustain this mortality without a population decline. During these years, 32 deer per year (not 52 as reported by Holroyd and Van Tighem 1983) were killed on the TCH. Of these 6 per year were killed on TCH III. The current (1987-89) TCH III kill is 12 per year. Therefore, either the mule deer population has increased in the interval or the rate of road-kills has increased in TCH III. As noted by Holroyd and Van Tighem (1983), the lack of adequate data on deer ecology continues to hamper assessment of mule deer population dynamics in the BVER.

No mule deer have been tagged or radio collared in the BVER. Casual observations made during this study suggest that they may have seasonal movement strategies similar to elk. Road-kill data (Appendix 11) illustrates that they are killed during every month of the year in the BVER, therefore, at least some mule deer probably do not migrate. However, the observation that few deer are killed during the winter months in the middle Bow Valley and that mule deer were observed on high elevation ranges only during summer, suggests that some BVER mule deer make seasonal return migrations. Gruell and Papez (1963) describe mule deer migrations similar to those observed by elk in mountainous areas. As can be seen from Figure 2, winter snow depth would severely limit mule deer mobility in the upper area of the BVER.

Giant liver flukes were found in BVER mule deer (Table 11). They were much less prevalent than in white-tailed deer.

6.4 WHITE-TAILED DEER

White-tailed deer were regularly seen during this study although no direct population estimates were made. If the assumption is made that white-tailed deer were equally susceptible as elk to collisions with automobiles on the TCH, then their relative abundance in the road-kill data from 1986-89 (Table 1) may be a reflection of their relative abundance in the BVER. If this is the case, their abundance relative to elk would be 0.18 (population estimate 162).

Holroyd and Van Tighem (1983) reviewed white-tailed deer status BNP and Jasper National Park and noted that they were "probably the least abundant ungulate" and that "the most significant source of mortality (for the species) is by far the automobile".

If road-kill data reflects relative abundance of white-tailed deer to mule deer, then white-tailed deer appear to have significantly increased during the years 1970-83 (ratio 1:6.9) to present (1984-88 ratio of 1:1.3). During the decade 1980-89, white-tailed deer road-kills increased relative to mule deer in Jasper and Kootenay national parks (CPS, unpubl. data).

No white-tailed deer have been tagged or radio collared in the BVER. Casual observations

made during this study suggest that they may have seasonal movement strategies similar to elk. Road-kill data (Appendix 9) illustrates that they are killed during every month of the year in the BVER, therefore, at least some white-tailed deer probably do not migrate. However, the observation that few deer are killed during the winter months in the middle Bow Valley and that occasional white-tailed deer were observed on high elevation ranges only during summer, suggests that some BVER white-tailed deer make seasonal return migrations. Halls (1984) noted that white-tailed deer make seasonal migrations in areas with marked seasonal differences in range quality. As can be seen from Figure 2, winter snow depth would severely limit white-tailed deer mobility in the upper area of the BVER.

Giant liver flukes were found in a high percentage of BVER white-tailed deer. White-tailed deer is a well known host for this parasite.

6.5 BIGHORN SHEEP

Bighorn sheep populations were addressed by the park warden service; therefore, no attempt to review their status will be made in this report. However, in assessing the effectiveness of the fence in reducing ungulate mortality, the park warden service have documented a significant number of cases where coyotes have apparently used the fence to facilitate predation on sheep.

Bighorn sheep livers were not inspected for giant liver flukes.

Table 8. Late winter elk population estimates*, BVER, 1985-89.

Date	DC	FRI_{DC}	IRI_{DC}	MRE	FRI_{MRE}	IRI_{MRE}
1985	795	-	-	-	-	-
1986	955	1.2	0.18	872	-	-
1987	891	0.9	-.07	946	1.1	0.08
1988	942**	1.1	0.06	919	1.0	-.03
1989	860***	0.9	-.09	909	1.0	-.01
Average****	889	-	-	912	-	-

* Direct counts (DC), ground mark-recapture elk population estimates (MRE), annual finite rate of increase (FRI), and annual instantaneous rate of increase (IRI).

** Two additional DC's in 1988 estimated 939 and 933.

*** 1 replicate DC in 1989 estimated 784.

**** Average population estimate from reconstruction based on highway deaths (see section 6.1.2.3) was 994.

Table 9. Classified elk counts in the BVER, 1985-1989.

Date	Total elk (herds)	Calf ratio* (limits)**	Age >0 M ratio (limits)	Age 1 M ratio (limits)	Age >1 M ratio (limits)
Autumn counts					
85 Oct 14-29	546 (54)	57.4 (+/-2.1)	48.7 (+/-8.2)	13.6 (+/-1.5)	35.1 (+/-5.0)
86 Nov 03-14	489 (35)	42.8 (+/-4.0)	37.6 (+/-14.6)	13.6 (+/-3.5)	24.0 (+/-8.5)
87 Oct 26-30	624 (47)	44.4 (+/-2.6)	27.6 (+/-7.5)	7.4 (+/-2.2)	20.1 (+/-4.8)
88 Oct 22-24	618 (48)	42.2 (+/-2.4)	23.9 (+/-5.6)	9.1 (+/-1.9)	14.8 (+/-3.3)
89 Nov 01-03	506 (26)	43.1 (+/-3.3)	31.4 (+/-20.8)	13.1 (+/-4.8)	18.3 (+/-10.3)
Spring counts					
86 Apr 17-22	488 (45)	23.8 (+/-3.0)	29.2 (+/-9.2)	11.9 (+/-2.0)	17.2 (+/-5.3)
87 Apr 27-29	487 (46)	29.8 (+/-4.2)	24.4 (+/-7.0)	7.0 (+/-1.6)	17.4 (+/-5.2)
88 Apr 19-20	440 (34)	21.8 (+/-3.6)	19.2 (+/-8.6)	7.4 (+/-2.0)	11.9 (+/-5.0)
89 Apr 26-28	531 (34)	24.5 (+/-4.5)	15.6 (+/-6.6)	7.7 (+/-2.3)	7.9 (+/-3.9)

* expressed in terms of per 100 adult female elk (age > 00)
** confidence intervals, $P < 0.05$
M adult male (age > 00)

Table 10. Elk years, deaths (D) and mortality rates (M*), and death category rank estimated from radio collared elk, BVER, 1986-89.

	Biological years				
	85-86**	86-87	87-88	88-89	85-89 (rank)
Elk years	7.78	39.56	44.6	41.71	133.65(n.a.)
D-total	2	8	4	4	18 (n.a.)
M-total	.257	.202	.090	.096	.135
D-TCH	1	3	1	0	5 (1)
M-TCH	.129	.076	.022	0	.037
D-CPR	0	0	0	2	2 (4)
M-CPR	0	0	0	.048	.015
D-other man	0	1	0	1	2 (4)
M-other man	0	.025	0	.024	.015
D-total man	1	4	1	3	9 (n.a.)
M-total man	.129	.101	.022	.007	.067*
D-wolves	1	3	0	0	4 (2)
M-wolves	.129	.076	0	0	.030
D-liver flukes	0	0	2	0	2 (4)
M-liver flukes	0	0	.045	0	.015
D-other natural	0	1	1	1	3 (3)
M-other natural	0	.025	.022	.024	0.023
D-total natural	1	4	3	1	9 (n.a.)
M-total natural	.129	.101	.067	.024	.067

* Elk years/deaths, no estimate of confidence intervals

** January 1986 to April 1986

Table 11. Prevalence of *Fascioloides magna* (FM), *Dictyocaulus viviparus* (DV) and *Echinococcus granulosus* (EG) in elk, moose, mule deer, and white-tailed deer in train- and road-kills, BVER, 1985-89.

Host Parasite	% Prevalence by age class (sample size) 00	01	02	>02
Elk				
FM	3	57	69	89
	(69)	(30)	(16)	(70)
DV	8	44	25	10
	(51)	(25)	(12)	(52)
EG	2	0	0	31
	(51)	(24)	(12)	(52)
Moose				
FM	100	-	-	100
	(1)	(0)	(0)	(6)
DV	0	-	-	0
	(1)	(0)	(0)	(4)
EG	100	-	-	25
	(1)	(0)	(0)	(4)
Mule deer				
FM	0	0	17	13
	(4)	(3)	(6)	(8)
DV	25	33	17	0
	(4)	(3)	(6)	(6)
EG	0	33	0	33
	(4)	(3)	(6)	(6)
White-tailed deer				
FM	-	20	50	83
	(0)	(10)	(2)	(6)
DV	-	0	-	0
	(0)	(6)	(0)	(3)
EG	-	0	-	0

Table 12. Percentage dry weight composition of elk diets in the BVER (BV) in 1987 based on fecal analysis* with corresponding data for elk diets in the Red Deer valley** (RD).

	Season							
Forage class	Dec-May		June		Jul-Aug		Sept-Nov	
	BV	RD	BV	RD	BV	RD	BV	RD
Grass&sedge	82.6	94.1	27.5	77.0	12.6	6.3	61.4	75.8
Salix spp.	1.2	1.5	9.9	10.5	21.5	88.6	6.2	1.0
Elaeagnaceae	3.2	-	54.5	-	62.3	-	30.0	-
Pinaceae	9.4	-	2.9	-	1.0	-	0.7	-
Subtotal shrubs	13.8	3.7	67.3	19.4	84.8	88.9	36.9	19.7
Forbs	3.6	2.2	5.2	3.6	2.8	2.6	1.7	4.5

* 16 samples (Dec-May), 3 samples (June), 6 samples (Jul-Aug), and 7 samples (Sept-Nov)

** RD samples from Ya-Ha Tinda range in winter and migratory ranges within BNP during other seasons, data from Morgantini (1988)

\- data not presented

Table 13. Percentage crude protein by dry weight in elk feces collected from the BVER, and from migratory ranges of BVER elk (BVER-M), 1985-88, with corresponding data for elk feces collected in the Red Deer valley*.

Month	BVER**	BVER-M	Red Deer
May	12.8	12.8	12.5
June	19.9	19.6	16.8
July	19.8	21.7	21.0
August	19.6	19.3	17.5
September	16.4	17.3	14.3
October	13.0	11.9	10.3
November	10.6	10.2	8.5
December	9.5	9.9	8.5
January	9.0	8.7	8.0
February	8.8	9.4	9.0
March	9.4	8.8	8.5
April	9.3	9.0	9.5

* Red Deer fecal samples from Ya-Ha Tinda Ranch area in winter and migratory ranges in the Red Deer drainage the rest of the year, data from Morgantini (1988)

** BVER data from Duthil, Grasslands, Golf Course and Hillsdale; BVER-M from high elevation range north of Cascade Mountain

Figure 6: Monthly distribution of TCH and CPR road kills and TCH trafic, 1985-89, BVER. Data presented in Appendix 8 and 9

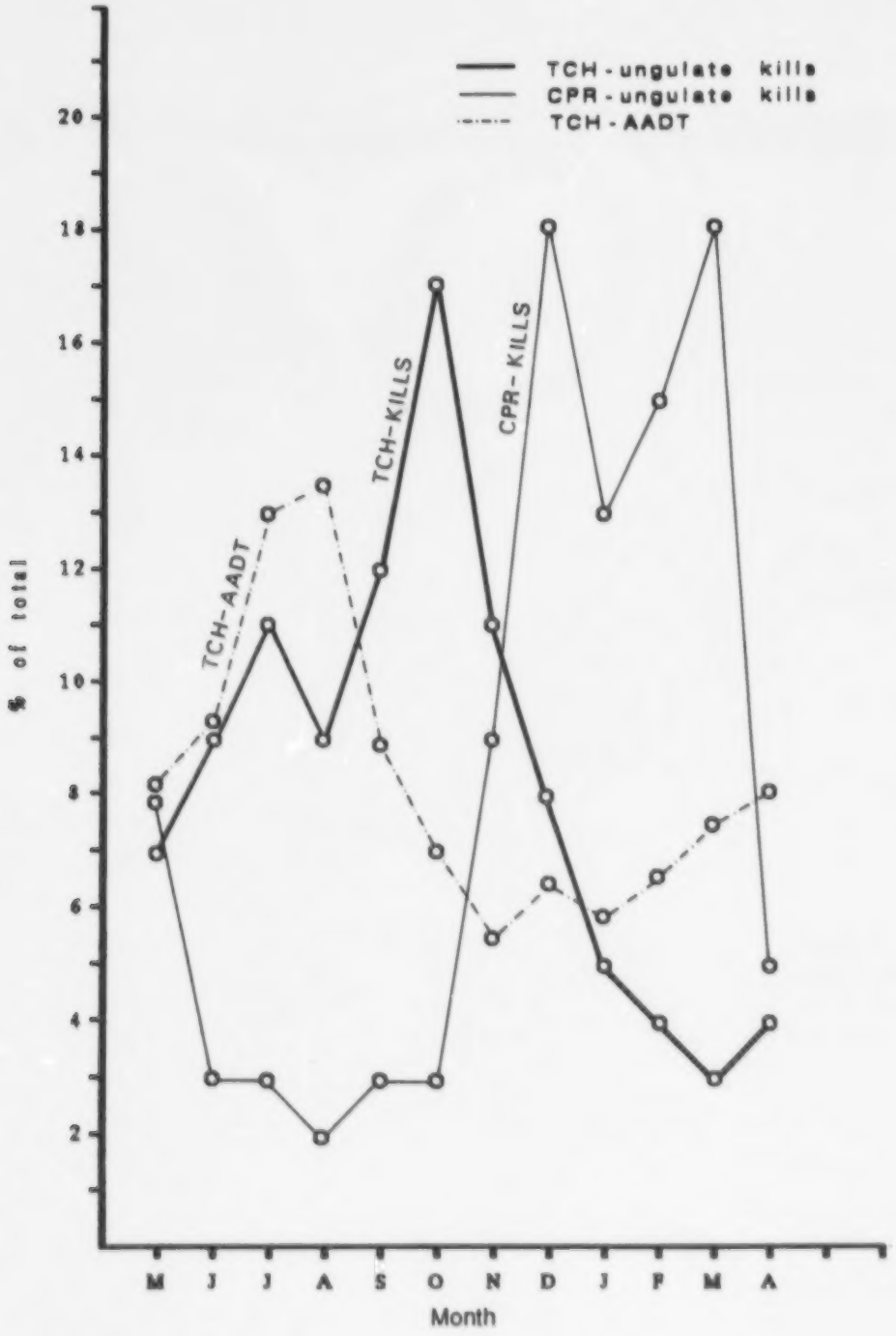
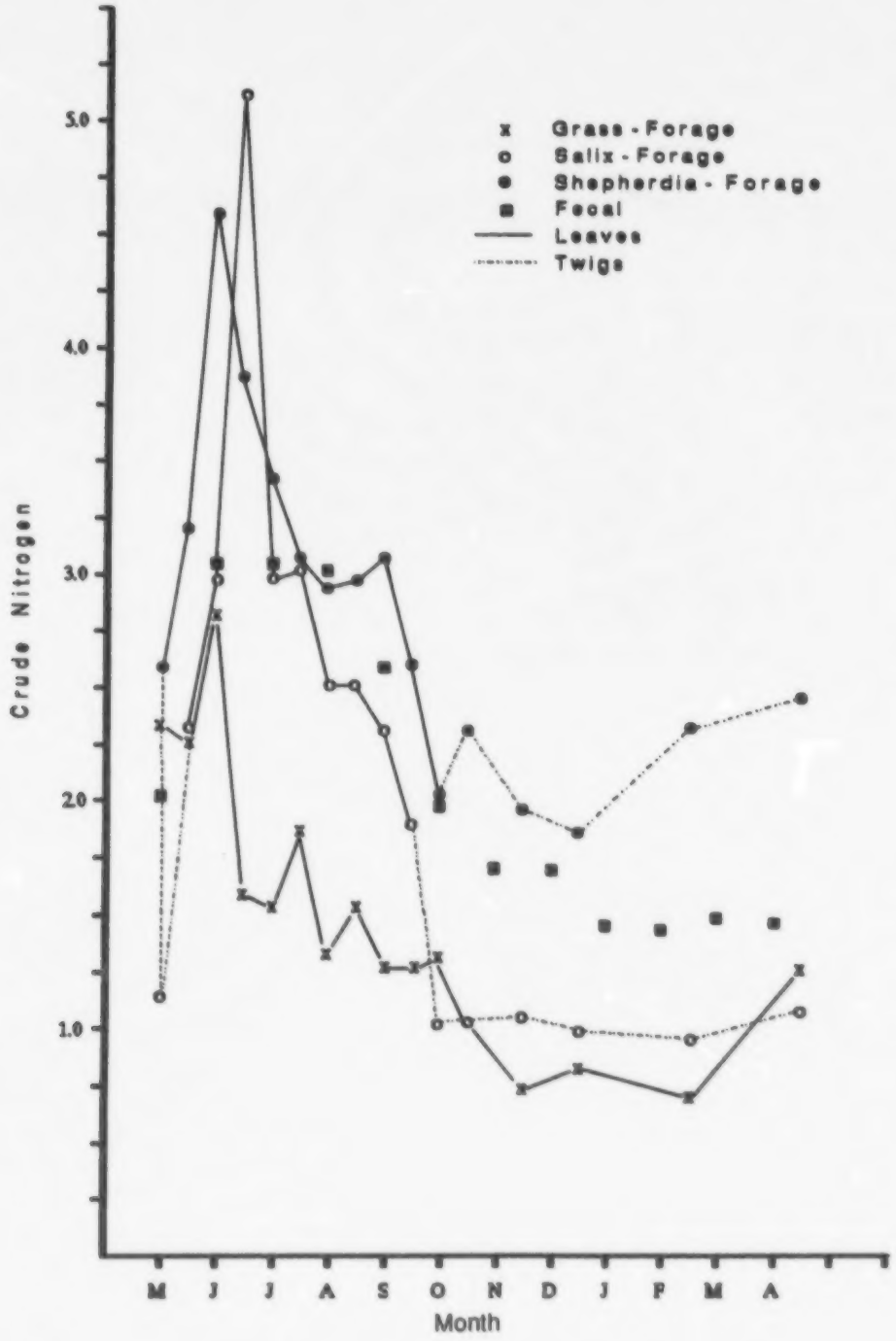


Figure 7: Crude nitrogin in forage and elk fecal samples, BVER, 1988



7.0 IMPACT ON ELK POPULATION DYNAMICS

7.1 PREVIOUS MODELS

Several models have been proposed to evaluate the impact of road-kill mortalities on ungulate populations. Holroyd (1979) noted estimates of potential net increase in elk populations ranged from 9 to 21%. He suggested that these figures could be used to estimate the maximum number of elk which could be removed from the population without collapse. Using road-kill data and population estimates from the 1970's, Holroyd (1979) projected elk population declines given the numbers of TCH and CPR road-kills at that time.

Damas and Smith (1982) suggested that road-kills be evaluated in terms of the annual increment. If they accounted for >50% of the increment they would be "significant"; 25-49% would be moderate; and <25% would be minor. To use this model of assessment, you must know the population size, all sources of additive mortality (CPR, TCH, sport hunting etc.), and the annual increment. These parameters are known for BVER elk, but the ranking based on fixed percentages is arbitrary.

Eberhardt (1985) presented a more complex view of the impact of mortality sources. He noted "..because survivorship of prime aged animals has by far the major impact on population growth, the best possible estimates should be sought there, only a few percentage points of adult survival separates increasing and decreasing populations." Merrill et al. (1987) observed that 5% additional adult mortality can have an effect on long-lived populations (such as elk).

The population model developed in this study, makes no a priori assumptions on acceptable levels of mortality (see Section 3.3). The model generates future population levels according to recruitment and mortality functions (Figure 8) and current population estimates.

7.2 RESULTS OF POPULATION MODELING

Four scenarios were explored using the deterministic elk population model outlined in the the Methods. Based on data presented in Chapter 6, the constant parameters used in exploring these scenarios were:

K_1 = 4,300 (mid-point, K_1 range 2,200 to 6,400)
$M_{natural}$ = 0.07
M_{cpr} = 0.015
N_{1990} = 900

M_{tch} was varied to generate the following scenarios:

a. Status quo_{1990} (M_{tch}=0.015)
b. Perfect fencing the entire TCH (M_{tch}=0.00)
c. Twin TCH III but do not fence (M_{tch}=0.03)
d. No fencing TCH I or II (M_{tch}=0.15).

Numerical and graphic results of these simulations are presented in Table 14 and Figure 9.

7.3 DISCUSSION OF THE STATUS QUO_{1990} SCENARIO

In this scenario, the constant M_{tch} allows the population to increase to 2,254 over 20 years. The only road-kills occur in TCH III and these kills increase with time from 20 per year at the start to 51 per year in 2010. (Note: in 1988-89 there were 23 road-kills.) Varying K_1 has little influence on road-kills at the start (18-21), but greatly influences road-kills in 20 years time (28-70).

An important assumption in this scenario is constant M_{tch}. If the number of elk collisions are directly related to traffic volume or traffic speed, then increases in TCH volumes or traffic speed would retard population growth and could become a significant population sink at some point in the future.

Bottini (1987b) presented evidence linking traffic volumes to road-kills in the BVER, however, a clearly defined relationship was not apparent. The traffic trend has been for increased volumes (Appendix 7) and PWC predicts a 20 year average increase of 3% per annum. Therefore, the M_{tch} used in these simulations may be too low.

Given the information currently in hand, this simulation demonstrates the positive effect of fencing on BVER elk populations.

7.4 DISCUSSION OF THE TOTAL FENCING SCENARIO

In this scenario, the constant M_{tch} (=0.00) allows the population to increase to 2,642 over 20 years. Although the assumption of perfect fencing is not reasonable, if present levels of fencing success are maintained (94-97%), then road-kills would be rare events and not feature in overall elk population dynamics.

Like the status quo scenario, this scenario demonstrates the positive effect of fencing on BVER elk populations.

7.5 DISCUSSION OF THE PARTIAL FENCING SCENARIO

In this scenario, the entire TCH is twinned, but only TCH I and TCH II are fenced. While the population model predicted an increased elk population (1,864), it reached a lower plateau than in the status quo scenario. Road-kills increased in time from 39 at the start to 86 in 20 years. Varying K_1 has little influence on road-kills at the start (35-41), but has a large influence in 20 years (49-116). As with the status quo scenario, if M_{tch} increases, the population would not perform as well as the model predicted.

7.6 DISCUSSION OF THE NO FENCING SCENARIO

This scenario is similar to the one suggested by Holroyd (1979) assuming total twinning with no fencing where a constant M_{tch} would cause the population to collapse. This simulation suggests a 20 year population of near 138 which supports Holroyd's projection of population collapse. Varying K_1 has little influence on this outcome (103-155). Road-kills are very high at the start (179) and then decrease to 39 as the population collapses. Any factor such as increased traffic speeds, traffic volumes, or increases in M_{tch} above 0.15 due to twinning, would accelerate the population collapse.

The significant conclusion from this simulation is that in an unmonitored situation, road-kills would decline over time and it might appear that the situation was self-correcting whereas the true explanation might be that the kills were causing a population crash.

Holroyd (1979) suggested that in the absence of fencing, moose populations might also crash in the BVER. Since moose populations are very small relative to elk, they would be more sensitive to rapid collapse. By the time this study commenced, moose were rarely seen in the BVER. Several mortality factors may have been responsible for this decline including CPR mortalities, giant liver fluke infestations, TCH mortalities, habitat changes and predators.

Table 14. Simulated elk populations and road-kills for the period 1991 to 2010 (N_{2010}) at 3 assumed levels of K_1. (see section 7.2)

Option	Assumed K_1 2,200	4,300	6,400
A. Status quo$_{1990}$			
N_{2010}	1,255	2,254	3,088
N trend(+/-)	+	+	+
Road-kill range	18-28	20-51	21-70
Road-kill trend(+/-)	+	+	+
B. Total TCH fencing*			
N_{2010}	1,443	2,642	3,704
N trend(+/-)	+	+	+
Road-kill range	0	0	0
Road-kill trend(+/-)	n.a.	n.a.	n.a.
C. Twin TCH III no fencing			
N_{2010}	1,079	1,864	2,497
N trend(+/-)	+	+	+
Road-kill range	35-49	39-86	41-116
Road-kill trend(+/-)	+	+	+
D. No TCH fencing			
N_{2010}	103	138	155
N trend(+/-)	-	-	-
Road-kill range	168-29	179-39	183-44
Road-kill trend(+/-)	-	-	-

* assumes perfect barrier

Figure 8. A population model for elk in the BVER. Arrows indicate annual sources of input and output from one May to the next

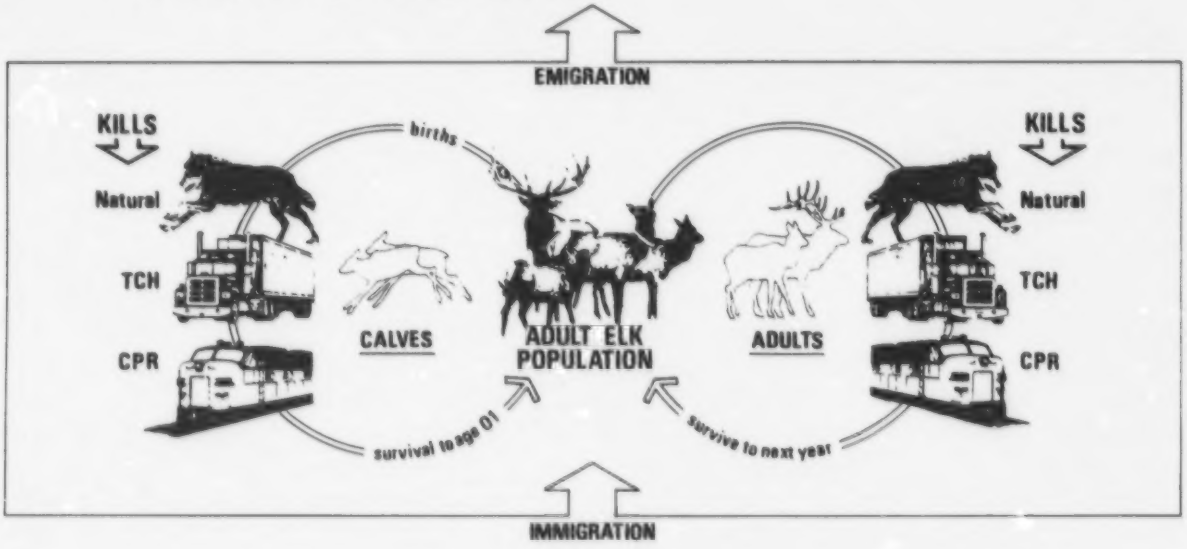
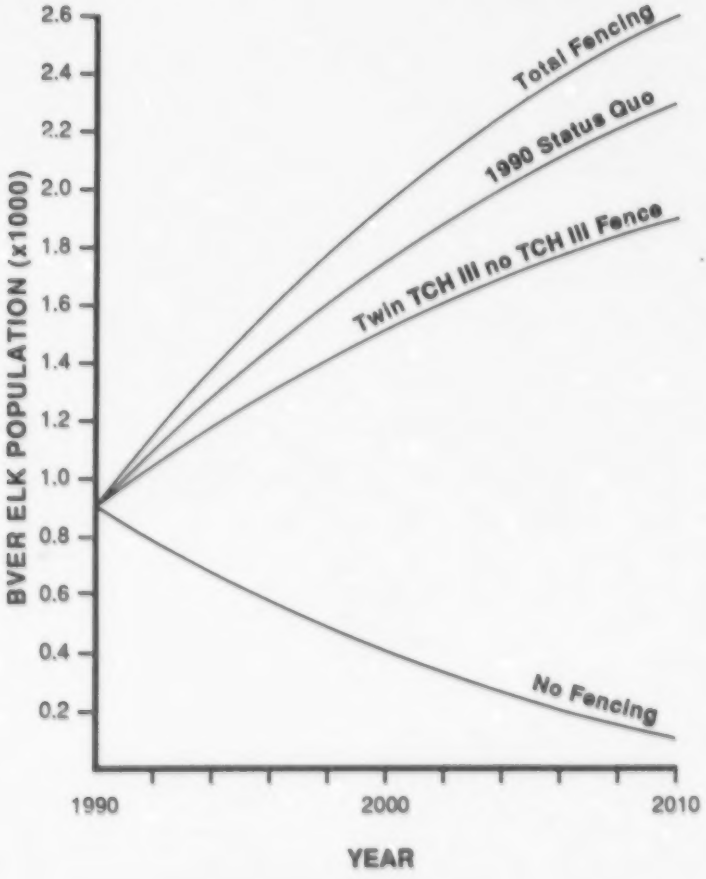


Figure 9. Example Elk population simulations. (K_1=4,300)



8.0 IMPLICATIONS FOR OTHER PROJECTS

8.1 TWINNING TCH III

Logan (1986), Flaa (1989), and Browne et al. (1989) have presented assessments of the impact of twinning TCH III and made specific recommendations. Browne et al. (1988) made use of the simulation model developed by this study.

Following the precedent of the environmental reviews for TCH I and TCH II, decisions to mitigate road-kills on a twinned TCH III will involve considerations of public safety and of the road-kill impact on wildlife populations (Browne et al. 1988). The recent cost benefit analysis of fencing and underpasses for a new twinned highway in BC, may provide additional guidance in this decision making (Clayton and Smith 1989).

8.1.1 FENCING

Fencing has proven effectiveness in TCH I and TCH II and Browne et al. (1988) have recommended fencing from the current end of fence to the Taylor Creek area if TCH III is twinned. With the exception of a study illustrating a reduction in night-time white-tailed deer kills using reflectors, fencing remains the only proven technique to reduce ungulate-vehicle collisions in the effectiveness ranges reported for TCH I and TCH II.

The significant increase (Table 3) in elk road-kills observed in TCH II when it was twinned but not fenced, is consistent with several reports in the literature on this topic. No design alteration (eg. wide medians, see Table 4) has been demonstrated to reduce twinning related increases in road-kills. Elk are generalist feeders and the wide diet choices made by elk (grass, sedges, shrubs leaves) make it likely that any type of median or road shoulder vegetation will have some attraction.

If TCH III is fenced, Texas gates will be required at the Highway 93 intersection. If an acceptable high-speed design is developed, installation of a Texas gate would be the surest way to end the TCH III fence. To be effective, Texas gates must not become filled with snow. Since snowfall is considerably greater in TCH III than in TCH I or TCH II, this factor should be taken into consideration in designing and maintaining TCH III Texas gates.

Fencing design for TCH III should take the greater snowpack depths in this area into consideration (Figure 2). Particularly at the west end of the project, winter snowpacks may develop which would allow ungulates to jump a 2.4 m fence.

Bellis and Graves (1971) in a study of white-tailed deer in Pennsylvania warned against fencing short sections of roads adjacent to crossing areas. They suggested that these sections might simply deflect animals to the fence ends and funnel them onto the road. The partial fencing approach used during the construction of TCH I and the resulting road-kills (B. Browne, CPS, pers. commun.) supports this warning. To overcome the problem, TCH II was constructed continuously from east to west. If all or part of TCH III is fenced, continuous fencing from the current TCH II end-of-fence would be the preferred option.

TCH III overlaps the ranges of 2 wolf packs (D. Huggard, University of BC, pers. commun.). This may result in more kills against the fence than was observed in TCH I and TCH II.

As can be seen from Table 15, ecosection representation along TCH III is highly atypical

of ecosection representation over the entire park. In addition, many of these ecosites are important to highly important to wildlife. For these reasons, the design and construction of a twinned TCH III should minimize land alienation. This suggests that the transportation corridor including the fence should be as narrow as possible and that gravel pit size should be minimized.

8.1.2 UNDERPASSES

The radio tracking data for elk in TCH III in this study (Table 5) illustrates several differences between elk movements and range use of TCH III compared to TCH II. Elk use in TCH III was concentrated north of the TCH (69-72% compared to 40-50%) and the average familiar area overlap was much greater (25-30 km compared to 8-9 km). Migration routes included a route up and down the valley, from the valley to the Mount Brett and Bourgeau cirques, into Kootenay National Park via Vermilion Pass, and into Yoho National Park via Kicking Horse Pass. Elk are also known to move between the valley and Redearth Creek.

Browne et al. (1988) recommended 4 underpasses on TCH III if it is twinned: at Wolverine Creek, at Redearth Creek, just east of Castle Junction, and at a site west of Castle Junction. R. Kunelius (PWC, May 1989, pers. commun.) made similar suggestions on underpass locations. The underpass system suggested by Browne et al. (1988) allows at least 1 underpasses adjacent to known migration routes and allows several underpasses within known annual familiar areas of elk (Table 16).

Underpass acceptance in TCH I and TCH II suggests that elk will utilize similar structures in TCH III. It is unknown if culvert underpasses of suitable dimensions (see section 2.5) will be as effective as bridge structures. Large culverts have been employed in a moose-deer fence-underpass situation in BC and have been used by both species of deer and moose (K.Simpson, Keystone Bioresearch, pers. commun.).

8.2 OTHER PROJECTS

The designs used in TCH I and TCH II have already been employed (with some modifications) on the Merritt-Peachland freeway in BC (B. Harper, BC Wildlife, pers. commun.).

An important difference between the BVER and many other areas, is the high degree of habituation by bighorn sheep, elk, and mule deer to humans. It is possible that the degree of underpass acceptance observed in the BVER may not be repeatable in a situation were animals are hunted and have little tolerance of humans. This habituation also may limit the effectiveness of reflectors, whistles and other scare devises in a park situation.

Van Tighem (1980) suggested fencing to reduce bighorn sheep train-kills in Jasper. However, it is possible that fencing TCH II may have increased predation and/or accidental bighorn sheep deaths (Banff warden serv. unpubl. data). Further experimentation with fence design and location in the Vermilion Lakes area of the TCH is required.

Table 15. Ecosection representation along the TCH III right-of-way based on existing park ecosite maps (Holland and Coen 1982) compared to park representation of ecosections and percentage of elk relocations mapped within TCH III ecosections.

Ecosection	%Park	%TCH III	%Elk locations
AL	0.8	11.9	14.9
AT	0.3	0.6	2.0
BK	2.8	17.4	6.2
BV	0.4	19.9	49.8
FR	0.2	4.9	24.5
HC	1.5	1.3	0.9
HD	0.5	2.8	5.6
IB	0.4	5.5	13.8
PP	1.7	2.8	1.7
PR	5.9	16.0	2.7
PT	0.8	0.6	0.8
SB	4.8	4.7	1.0
VL	0.5	2.8	5.6

Table 16. Elk familiar area* overlap with a hypothetical underpass distribution in TCH III.**

Elk code name	Underpass location (PWC km)			
	29.6	37.0	47.3	50
Backswamp	X	X	X	X
Castle	-	X	X	X
Langshaw	X	X	X	X
Rudolph	X	X	X	-
Skinny	-	-	X	X
Terry	X	X	X	X
Ticker	X	X	X	X
Tremble	X	X	X	X

* elk FA's based on radio tracking in TCH III, BVER, 1986-89.

** X overlapped, - did not overlap

9.0 SUMMARY

9.1 FENCING

* The fence system installed in TCH I and II reduced ungulate road-kills by 94-97%. This is the highest estimate of success for any reported project of this type.

* The active removal by the park warden service of animals trapped within the fence contributes to the project's success.

* The fence reduced total mortality rates for elk.

* The fence may have increased coyote predation on bighorn sheep.

* The number of elk and bighorn sheep road-kills significantly increased on TCH II when it was twinned, but not fenced. Mule deer and white-tailed deer road-kills did not significantly increase.

* On the twinned highway before fencing, elk road-kills were not significantly related to the type of median (grassed or concrete) in the collision area.

* The end-of-fence at the East Gate is an unresolved problem. A Texas gate of acceptable design for the TCH would solve the problem and be valuable in other areas.

* Since snowfall and snowpack increases between Banff and Lake Louise, snowpack may reduce the effectiveness of a 2.4 m fence in TCH III during winters with exceptionally deep snow and crusted snow.

* If Texas gates become snow-filled, their effectiveness is reduced. This problem will increase from east to west in the BVER unless the Texas gates are designed in expectation of heavier snowfall.

9.2 UNDERPASSES

* Bighorn sheep, deer, elk, and moose made use of underpasses before and after fencing.

* Elk in the BVER have complex movement strategies. Some are resident in the valley, others migrate, and some switch strategies between years. Underpasses installed in TCH I and TCH II allowed continued use of seasonal ranges after fencing for all characteristics studied except the highway crossing index. This suggested that the relative frequency of highway corridor crossings decreased after fencing.

* Track studies conducted by the park warden service indicated few similarities of underpass use by elk and deer. Elk use was highly different from underpass to underpass.

* Available data does not demonstrate that open-span underpasses are more acceptable to ungulates than culvert underpasses of suitable dimensions. A trial comparing the 2 designs has never been conducted and the relatively less use of Morrison Coulee observed in the warden service track study could be explained by local site characteristics.

* Elk and white-tailed deer made use of an overpass unintentionally created by a CPR bridge at the Minnewanka Interchange.

9.3 UNGULATE POPULATION BENCHMARKS

9.3.1 ELK

* Three methods of estimating spring BVER elk populations resulted in estimates ranging from 795 to 1101 during the years 1985-89.

* For the interval 1985-89, the finite rate of elk population increase varied from 0.9 to 1.2.

* Calf-cow ratios, yearling bull-cow ratios, and adult bull-cow ratios were significantly higher in the autumn than in the spring.

* Collisions with automobiles were the leading cause of death for radio collared elk. TCH road-kill mortality reduced from 0.103 before fencing to 0.011 after fencing. Significantly more calves were killed on the TCH than were observed in any classified elk count.

* Giant liver flukes have significantly increased in prevalence when compared to 1940's-1960's. Eighty-nine percent of adult elk (age >01) examined during 1985-89 had giant liver flukes. Two radio collared elk were diagnosed as dying from extreme liver damage due to the presence of high numbers of flukes.

* Predation by timber wolves was the leading natural cause of death for radio collared elk during the study. The age and sex distribution of elk killed by wolves was significantly different from classified counts at any season. More calves and adult bulls were killed than were present in either the classified samples or the hypothetical conception rates.

* CPR train-kills were dissimilar from TCH road-kills in terms of species composition, timing, and age distribution. CPR train-kills were primarily elk, peaked in the winter rather than the autumn, and had calf-cow ratios similar to late winter classified elk count ratios. Experience gained in 1971-72 in the BVER (see section 6.1.1) indicated that CPR train-kills may dramatically increase during winters with extreme snow conditions.

* Migrations and dispersals of BVER elk illustrated considerable trans-boundary impact of elk management within the park. BVER elk wintering along the TCH make summer migrations outside the park to the Spray Lakes, AB and across the Continental Divide into Mount Assiniboine Provincial Park, Kootenay National Park, and Yoho National Park in BC.

* Seasonal movements of BVER elk are dissimilar from Red Deer River valley elk in terms of percentage migrating, migration timing, and the lack of "intermediate" ranges for BVER elk

* Details on BVER elk diets are presented. Leaves predominate in BVER elk diets all year. The blades of grasses and sedges are the most frequent forage classes during the autumn through spring. During the summer, the leaves of buffaloberry (*Shepherdia canadensis*) and willows (*Salix* spp.) are the most frequent forage groups represented in fecal samples. As a generalist mixed feeder, elk are likely to make some use of any vegetation type employed on highway medians and road shoulders.

* Fecal protein values for BVER elk closely parallel values presented by Morgantini (1989) for the Red Deer River valley elk population.

* Forage quality of grasses, willow, and buffaloberry in the BVER are presented. These data illustrate the nutritional advantage of diet switching from grasses to shrub leaves during the summer months.

* Body weights and antler weights are indistinguishable from those reported by Flook (1967) for the BVER in the 1960's. Jaw lengths are presented for future comparisons.

* The ecological carrying capacity of the BVER for elk has been debated for many years. It cannot be determined without removing significant human-related sources of elk mortality and observing the system.

9.3.2 MOOSE

* Moose are scarce in the BVER and apparently fewer in number than in the late 1940's. Moose are currently so few in number that they may not be a definable population for management purposes.

* Extensive liver damage by giant liver flukes may be increasing natural moose mortality in the BVER.

9.3.3 MULE DEER

* Mule deer are commonly seen in the BVER and frequently killed on the TCH.

* Little is known about mule deer ecology in the BVER.

* Mule deer have the lowest prevalence of giant liver fluke of any BVER cervid.

9.3.4 WHITE-TAILED DEER

* White-tailed deer are commonly seen in the BVER. Their prevalence in TCH road-kills has greatly increased over the past 2 decades.

* White-tailed deer are a well documented host of giant liver fluke in the BVER and elsewhere.

* White-tailed deer have been observed using the CPR bridge at the Minnewanka Interchange.

* Little is known about white-tailed deer ecology in the BVER.

9.3.5 BIGHORN SHEEP

* Bighorn sheep distribution overlaps the TCH in 1 location in TCH II. While the fence eliminated road-kills at this location, there is a current concern that it may be facilitating coyote predation rates. This topic is being investigated in detail by the park warden service.

9.4 IMPACT ON ELK POPULATION DYNAMICS

* Population modeling illustrated the potential of fencing to increase BVER elk populations. As predicted by Holroyd (1979), the model suggests population collapse in the absence of any TCH fencing.

9.5 IMPLICATIONS FOR OTHER PROJECTS

* Fencing and underpass successes experienced in TCH I and TCH II can be employed in the designs for TCH III; increased snowpack in TCH III should be taken into consideration

* Ecosection representation along TCH III is highly atypical of the park. These habitats are scarce resources at the park level. Designs should be favoured which minimize alienation of natural ecosites.

* If TCH III is fenced totally or in part, basic data on elk home range configurations and migration routes provided in this report can aid in underpass location and frequency decisions. These data illustrate the historic and continuing importance of Vermilion Pass as a migration and dispersal route for BVER elk.

* Habituated ungulates such as bighorn sheep, elk, and mule deer in park settings may react differently to automobiles, trains, fences, and underpasses than ungulates in areas where there is sport hunting.

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APPENDICES

Appendix 1. Snowfall (cm) at Banff townsite*, 1985-89,1971-72**, and long term average (LTA).

	Winter					
Month	85-86	86-87	87-88	88-89	71-72	LTA
September	10.0	5.4	0.0	13.2	13.2	6.2
October	29.4	9.4	2.0	6.0	50.3	17.8
November	23.6	72.2	3.8	10.8	23.9	32.2
December	1.4	4.4	42.4	43.6	81.3	45.0
January	19.8	12.6	26.0	53.8	83.6	44.1
February	39.0	19.6	12.8	15.6	142.0	32.8
March	13.2	25.2	26.8	21.2	37.8	24.8
April	22.6	25.2	15.2	40.6	18.5	31.6
May	30.0	2.6	16.0	1.2	4.8	14.3
Total	189.0	176.6	145.0	206.0	455.4	248.9
%LTA	76	71	58	83	183	100

*data from Environment Canada weather station, Banff
**greatest snowfall in twenty year period 1970-89

Appendix 2. Snowpack (cm)* at Banff townsite**, 1985-89 and 1971-72***.

	Winter				
Month	85-86	86-87	87-88	88-89	71-72
September	00-00	00-00	00-00	03-00	00-00
October	07-00	04-00	02-00	03-00	25-00
November	16-00	34-00	03-00	08-00	23-00
December	16-04	30-00	20-00	24-00	43-00
January	24-10	36-27	34-16	33-24	74-36
February	40-14	39-24	25-08	33-28	124-48
March	14-00	41-00	12-00	36-06	124-13
April	04-00	16-00	03-00	06-00	13-00
May	08-00	01-00	00-00	00-00	00-00

*maximum-minimum for the month
**data from Environment Canada weather station, Banff
***greatest snowfall in twenty year period 1970-89

Appendix 3. Snowfall (cm) at Lake Louise townsite*, 1985-89 and long term average (LTA).

	Winter				
Month	85-86	86-87	87-88	88-89	LTA
September	0	0	0	0	4.8
October	75.0	12.0	0.5	13.9	30.6
November	54.0	116.0	7.5	34.0	66.8
December	9.0	31.0	59.0	44.5	97.8
January	51.0	51.5	48.0	97.5	78.2
February	47.0	17.0	29.0	21.0	51.5
March	41.5	23.0	25.5	55.0	41.5
April	5.0	8.0	40.0	29.5	33.7
May	9.0	1.0	0	0	12.7
Total	291.5	259.5	209.5	295.4	417.6
%LTA	70	62	50	71	100

*data from park warden service, Lake Louise

Appendix 4. Snowpack (cm)* at Lake Louise townsite**, 1985-89

	Winter			
Month	85-86	86-87	87-88	88-89
September	00-00	00-00	00-00	00-00
October	42-00	13-00	00-00	00-00
November	50-28	68-03	07-01	25-00
December	46-42	60-47	45-06	48-20
January	75-44	85-58	68-36	76-48
February	97-65	84-74	75-55	83-70
March	84-74	92-71	61-53	100-78
April	70-00	65-00	65-00	90-10
May	03-00	00-00	00-00	00-00

*maximum-minimum for the month
**data from park warden service, Lake Louise

Appendix 5. Maximum monthly snowpack (cm)* at Mount Norquay (MN) and Sunshine (SS) ski areas, BVER, winters of 1985-89.

Month	Winter Area-Area 85-86 MN-SS	86-87 MN-SS	87-88 MN-SS	88-89 MN-SS
September	- -	- -		
October	- -	- -		
November	43-135	65-118	07-35	18-60
December	42-130	55-105	40-92	40-120
January	58-165	68-131	58-136	70-160
February	78-208	75-150	61-166	90-165
March	68-222	87-160	63-184	90-175
April	-220	67-183	65-189	90-210
May	-255	-140	-146	-162

* data from park warden service

Appendix 6. TCH road log*, BVER, 1983-87.

Km from East Gate		PWC Km	U.T.M.	Description (reads from east to west)
TCH EAST				
35.2	-		PG-387-631	Junction Hwy 40 overpass, 4 lanes, grass median, 110 km/hr, no illumination, no ungulate proof fencing
32.0	-		PG-363-610	Kananaskis River bridge, Bow Valley Park starts
31.2	-		PG-363-603	Junction 1X overpass
26.7	-		PG-319-591	Bow Valley Park ends, Lac Des Arcs rock cuts start
15.5	-		PG-223-554	Dead Man's Flats junction, overpass
10.0	-		PG-175-580	Bow River bridge
8.6	-		PG-169-593	Canmore Eastern Access junction
6.7	-		PG-166-598	Cougar Creek overpass
4.8	-		PG-148-623	highway illumination starts
3.9	-		PG-142-632	Canmore Western Access junction TCH East-BVE
3.9	-		PG-142-632	Canmore Western Access junction
2.8	-		PG-135-640	6 lanes start, concrete median starts
1.2	-		PG-123-651	8 lanes start
0.0	-		PG-114-658	East Gate, 4 lanes, grass median, 90 km/hr, no illumination, ungulate proof fencing starts
TCH I				
0.0	0.0		PG-114-658	East Gate, 4 lanes, grass median, 90 km/hr, no illumination, ungulate fencing starts, fence construction started here June 1983
0.3	-		PG-113-661	East Gate wildlife underpass (bridge type) north
0.4	-		PG-112-661	East Gate wildlife underpass (bridge type) south
1.0	-		PG-108-666	reduction to 2 lanes each way
2.2	2.5		PG-098-675	Carrot Creek bridge, wildlife path completed October 1985
3.7	4.0		PG-089-688	Morrison Coulee wildlife underpass (culvert type)
6.1	6.5		PG-069-701	Duthil wildlife underpass (bridge type), fence complete December 1983
6.7	-		PG-065-705	fence crosses CPR line, crossing relocated here January 1987
11.0	11.3		PG-035-732	Powerhouse wildlife underpass (bridge type), ungulate proof fencing end in Dec 1984, fencing construction starts again September 1986
TCH II				
11.0	11.3		PG-035-732	Powerhouse wildlife underpass (bridge type), ungulate proof fencing construction start October 07,1986, proceeding west
11.6	-		PG-031-736	concrete median starts
12.0	12.4		PG-028-739	Cascade River spillway bridge, illumination starts traffic July 1985
13.1	-		PG-019-734	illumination ends
14.5	14.9		PG-012-726	Grasslands wildlife underpass (bridge type)
14.7	15.2		PG-009-725	Buffalo Paddock intersection
15.0	15.7		PG-005-722	40 Mile Creek bridge
16.4	-		NG-992-716	illumination begins

Appendix 6. TCH road log*, BVER, 1983-87. (continued)

Km from East Gate	Km PWC	U.T.M.	Description (reads from east to west)
TCH II			
16.7	17.5	NG-989-714	Norquay Road intersection overpass, ungulate proof fencing completed to this point December 19, 1987, fencing continues April 1987
16.9	-	NG-987-713	illumination ends, speed reduction zone starts (70 km/hr), reduction removed October 1985
18.1	19.0	NG-975-708	Vermilion wildlife underpass (bridge type)
21.1	22.1	NG-950-700	Edith wildlife underpass (bridge type)
21.4	-	NG-946-698	grass median begins, opened to 4 lane traffic October 29, 1985; end of speed reduction zone (70 km/hr), reduction removed October 29, 1985
22.3	23.7	NG-938-692	Five Mile bridge
23.8	24.5	NG-926-683	Healy wildlife underpass (bridge type)
24.8	25.5	NG-917-677	Sunshine ski area overpass
26.1	27.0	NG-910-680	ungulate proof fencing ends, fence construction completed to this point September 1987, 2 lanes begins
TCH IIIA			
26.1	27.0	NG-910-680	ungulate proof fencing ends, 2 lanes begins
28.7	29.6	NG-884-696	Wolverine Creek bridge
36.4	37.3	NG-829-751	Redearth Creek bridge
46.0	47.0	NG-746-795	Castle Junction overpass, Hwy 93 South
TCH IIIB			
46.0	47.0	NG-746-795	Castle Junction overpass, Hwy 93 South
53.9	55.3	NG-681-843	Taylor Creek bridge
62.8	64.3	NG-622-909	Moraine Creek bridge
67.8	-	NG-588-946	Bow River bridge
68.2	-	NG-587-950	CPR underpass
69.7	-	NG-579-962	4 lanes begins, narrow grass median
70.8	-	NG-576-973	Lake Louise overpass
71.3	72.8	NG-572-976	Pipestone River bridge
71.8	-	NG-568-978	2 lanes begins
73.4	74.7	NG-559-988	Hwy 93 North overpass
73.8	-	NG-555-989	CPR overpass
74.2	-	NG-549-990	Bow River bridge
74.8	-	NG-542-991	CPR cuts start
75.6	-	NG-534-992	CPR underpass
78.6	-	NH-513-006	CPR cuts end
78.9	-	NH-510-008	Bath Creek bridge
79.5	-	NH-503-004	CPR underpass
80.2	81.6	NH-497-002	Continental Divide

* information based on notes provided by R. Iverson, PWC and R. Kunelius,CPS

Appendix 7. Two-way annual average daily traffic (AADT), TCH, East Gate*, BVER, calendar years 1970-88.

Year	AADT	Change (%)
1970	5060	+9.4
1971	5535	+0.8
1972	5580	+8.4
1973	6050	+9.6
1974	6630	+2.5
1975	6795	+11.9
1976	7600	+5.0
1977	7980	+5.0
1978	8120	+1.8
1979	9610	+18.3
1980	9950	+3.5
1981	10850	+9.1
1982	10540	-2.9
1983	10140	-3.8
1984	9690	-4.4
1985	10050	+3.7
1986	10290	+2.4
1987	10802	+5.0
1988	11234	+4.0

* Traffic volumes in TCH IIIA and TCH IIIB were 0.72 and 0.53 of East Gate traffic based on SADT (summer average daily traffic) data from 1987-88 (M. Brunell, CPS, unpubl. data, 1990).
Traffic volumes in TCH II, TCH IIIA, and TCH IIIB were 0.84, 0.77, and 0.70 of East Gate traffic based on 1982 data (Brunell 1982).

Appendix 8. Two-way monthly average daily traffic (MADT) for the TCH at East Gate, BVER, 1985 - 89.

	Year				
Month	85-86	86-87	87-88	88-89	% Total
May	9428	10451	10551	10972	8.2
June	11108	11604	12129	12151	9.3
July	14926	16035	16463	18232	13.0
August	16309	17787	17104	17322	13.6
September	9531	10572	12182	12354	8.9
October	7441	9039	9413	9820	7.1
November	6019	6421	7281	7412	5.4
December	7868	8650	7121	8864	6.5
January	5896	8549	7633	7619	5.9
February	7083	9038	9726	8036	6.7
March	8198	9015	9544	10595	7.4
April	9020	10774	10603	10337	8.1

Appendix 9. Ungulate road-kills and train-kills, BVER, calendar years 1970-88.

Year	TCH						CPR				
	Elk	WTD	MD	BS	MO	Total	Elk	WTD	MD	MO	Total
70	12	1	5	4	5	27	3	0	0	0	3
71	21	2	13	6	7	49	25	0	0	9	34
72	8	0	8	8	4	28	80	0	5	12	97
73	7	0	11	4	1	23	6	0	0	0	6
74	17	1	19	11	5	53	10	0	0	2	12
75	29	2	26	12	2	71	17	0	0	2	19
76	26	2	31	16	0	75	4	0	0	3	7
77	37	3	26	7	2	75	6	0	1	0	7
78	46	7	39	7	1	100	17	0	1	2	20
79	59	6	37	4	6	112	13	2	1	0	16
80	60	8	33	8	7	116	41	0	0	2	43
81	44	7	25	11	3	90	18	0	0	3	21
82	48	5	31	10	2	96	11	0	1	0	12
83	48	3	20	14	2	87	9	0	1	0	10
84	56	9	11	9	2	87	25	2	0	0	27
85	66	9	12	3	5	95	34	0	0	1	35
86	106	11	14	17	1	149	44	0	3	0	47
87	44	10	15	12	2	83	45	3	3	0	51
88	26	12	14	0	1	53	24	2	1	0	27
T	760	98	390	163	58	1469	432	9	17	36	494

WTD = White-tailed Deer, MD = Mule Deer, BS = Bighorn Sheep, MO = Moose. Data for the period 1970 to 1984 from Banff National Park warden files, 1985 to 1988 from this study. 1977-84 data revised by R. Kunelius.

Appendix 10. Wilcoxon ranked pairs and McNemar's test for between years comparisons of movement behavior for paired samples of radio tracked elk, TCH II, 1986-88.

Behavior	86x87	86x88	87x88
Total Familiar Area			
Average km²	71-66	72-64	58-63
Total Pairs	19	18	27
P	0.87	0.78	0.47
Ho:	n.s.	n.s.	n.s.
BVER Familiar Area			
Average km²	30-26	28-27	23-28
Total Pairs	19	18	27
Wilcoxon T	0.21	0.48	0.18
Ho:	n.s.	n.s.	n.s.
Length of Overlap of Familiar Areas with TCH II			
Average km	8-8	8-8	8-8
Total Pairs	21	19	28
P	0.90	0.59	0.79
Ho:	n.s.	n.s.	n.s.
Percent of Locations North of TCH II			
Average (%)	34-36	36-34	37-32
Total Pairs	20	19	30
P	0.70	0.34	0.04
Ho:	n.s.	n.s.	S
HCI			
Average Index	8-4	9-5	3-4
Total Pairs	20	19	30
Wilcoxon T	<0.001	<0.001	0.03
Ho:	S	S	S.
Summer Migration Departure Date			
Average	155-146	158-161	156-164
Total Pairs	7	8	11
P	0.07	0.94	0.31
Ho:	n.s.	n.s.	n.s.
Summer Migration Return Date			
Average	264-264	261-253	268-258
Total Pairs	7	8	11
P	0.93	0.37	0.06
Ho:	n.s.	n.s.	n.s.
Number of BVER Familiar Areas Overlapping TCH II			
Total pairs	20	19	30
Changed status	4	5	3
Chi²	2.25	3.20	0.00
Ho:	n.s.	n.s.	n.s.

n.s. not significant

S significantly different between pairs, $P < 0.05$

Appendix 11. Monthly distribution of train- and road-kills*, BVER, 1985-89.

Species-Cause	% of total											
	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Elk												
TCH	4	4	11	7	16	22	10	11	6	4	3	3
CPR	8	4	2	2	1	3	9	18	14	15	19	6
Moose												
TCH	25	13	13	13	0	13	13	0	13	0	0	0
CPR	0	0	0	0	0	0	100	0	0	0	0	0
Mule deer												
TCH	14	20	7	19	7	12	10	5	2	2	0	3
CPR	0	0	13	0	38	13	13	13	0	0	13	0
White-tailed deer												
TCH	14	14	18	6	4	8	16	2	10	0	4	4
CPR	20	20	0	0	0	0	0	20	40	0	0	0
Bighorn sheep												
TCH	3	13	13	13	6	3	13	3	3	6	9	16
CPR	-	-	-	-	-	-	-	-	-	-	-	-
All ungulates												
TCH	7	9	11	9	12	17	11	8	5	4	3	4
CPR	8	3	3	2	3	3	9	18	13	15	18	15

* road-kill sample: 254 elk, 8 moose, 59 mule deer, 50 white-tailed deer, 32 bighorn sheep, 403 total ungulates; train-kill sample: 138 elk, 1 moose, 8 mule deer, 5 white-tailed deer, 0 bighorn sheep, 152 total ungulates

Appendix 12. Age distribution of elk train- and road-kills,BVER, 1985-89.

Age class	TCH road-kills			CPR train-kills		
	Female	Male	Both	Female	Male	Both
00	50	42	92	10	4	14
01	17	22	39	6	14	20
02	8	5	13	9	1	10
03	9	7	16	7	2	9
04	7	1	8	4	0	4
05	6	7	13	2	2	4
06	7	4	11	4	4	8
07	7	5	12	3	2	5
08	3	3	6	2	0	2
09	3	1	4	2	0	2
10	5	0		2	1	3
11	0	0	0	2	0	2
12	3	0	3	1	0	1
13	0	0	0	0	1	1
14	0	0	0	1	0	1
15	2	0	2	0	0	0
16	3	0	3	0	0	0
17	0	0	0	1	0	1
18	1	0	1	0	0	0
19	0	0	0	2	0	2
20	0	0	0	0	0	0
21	1	0	1	0	0	0
22	0	0	0	1	0	1
Adult	5	6	11	3	2	5
Unknown	6	0	6	6	0	6
Subtotal 01-22	87	61	148	52	29	81

Appendix 13. Body weights (kg) of BVER elk*, 1960's and 1985-89.

Age	Sample		Average		+/- **		Maximum		Minimum	
	60's	80's	60's	80's	60's	80's	60's	80's	60's	80's
Males										
00	41	23	121	105	4	17	164	150	14	30
01	41	16	203	170	7	20	250	222	161	92
02	21	5	257	221	13	36	305	244	203	182
03	12	7	305	280	20	30	361	420	250	230
04	14	0	313	-	13	-	346	-	275	-
05	14	3	329	351	16	46	380	358	282	345
06	7	4	332	403	25	40	*382*	*471*	286	360
07	5	5	350	351	25	36	375	376	321	335
08	8	2	332	341	23	56	368	377	332	304
09	5	1	368	401	39	-	309	401	273	401
10	5	0	346	-	11	-	359	-	336	-
03-10	70	22	328	339	20	42	382	471	250	230
Females										
00	29	23	118	94	4	14	142	148	103	10
01	38	5	188	147	5	29	263	194	154	87
02	45	6	232	186	5	27	275	220	189	160
03	38	4	238	221	7	33	279	240	188	195
04	30	5	255	234	5	37	282	265	225	192
05	29	5	261	225	9	30	316	243	225	205
06	18	4	264	255	11	33	300	*311*	232	220
07	14	3	268	234	13	38	318	250	232	168
08	14	3	259	209	14	38	*321*	249	221	168
09	13	2	261	265	14	47	318	270	221	259
10	15	3	250	285	13	38	289	310	214	272
03-10	171	29	255	238	10	36	321	311	188	168

* 1960's data estimated from graphs presented by Flook (1967) excluded antler weight. 1980's data from this study included antler weight.

** confidence interval, $P < 0.05$

Appendix 14. Antler weights* (kg) for elk train- and road-kills, 1985-89.

Age	1980's			1960's		
	Sample	Mean	+/-**	Sample	Mean	+/-
01	14	0.20	0.28	51	0.19	0.05
02	2	0.61	0.74	23	0.70	0.09
03	12	1.01	0.30	13	1.44	0.19
04	3	2.28	0.60	14	1.63	0.23
05	7	2.66	0.39	15	2.37	0.44
06	8	2.65	0.37	6	2.83	0.35
07	8	2.98	0.37	7	3.77	0.70
08	7	3.41	0.40	7	3.30	0.93
09	5	3.60	0.47	5	2.74	1.14
10	2	3.19	0.74	5	3.58	0.58

* Corresponding data estimated from graphs presented by Flook (1967), BVER, 1960's. This study used 1 side dry weights; Flook (1967) presented both side wet weights; Flook's data was transformed by dividing by 2 (to give average weight of 1 antler) and multiplying by 0.97 to adjust wet weight to dry weight.

** confidence interval, $P < 0.05$

Appendix 15. Antler points* for elk train- and road-kills, BVER, 1985-89.

Age	Number of points						
	1	2	3	4	5	6	7
01	24	-	-	-	-	-	-
02	-	-	1	1	-	1	-
03	-	-	-	1	7	1	-
04	-	-	-	-	1	-	-
05	-	-	-	-	2	5	1
06	-	-	-	-	-	7	-
07	-	-	-	-	1	5	1
08	-	-	-	-	-	5	-
09	-	-	-	-	1	0	-

* left antler

Appendix 16. Jaw lengths for elk train- and road-kills, BVER, 1985-89.

Age Class	Jaw lengths(mm)		
	Sample	Mean	+/-*
Males			
00	29	250	5
01	18	302	7
02	6	329	11
03	6	348	12
04	1	364	-
05	5	359	12
06	5	364	12
07	4	371	13
08	2	365	19
09	1	371	27
10	1	361	27
Females			
00	26	244	6
01	13	303	9
02	15	324	8
03	12	333	9
04	9	337	11
05	7	341	12
06	9	344	11
07	5	344	14
08	5	343	14
09	3	355	18
10	6	353	12

* confidence interval, $P < 0.05$

Appendix 17. Average kidney fat indices (KFI) for elk age >02 train- and road-kills, BVER, 1985-89.

Month	Males		Females	
	KFI	Sample	KFI	Sample
May	-	0	1.3	3
June	-	0	1.1	1
July	2.6	1	1.5	3
August	2.6	1	1.2	1
September	3.0	2	2.4	5
October	1.4	5	4.7	3
November	1.3	3	2.9	5
December	2.7	1	3.0	6
January	1.7	2	2.4	5
February	1.4	2	1.3	1
March	1.5	2	1.9	4
April	-	0	1.4	4